BRITISH WELDING JOURNAL

1960 | APRIL

VOL. 7 | NO. 4

CONTENTS

Reclamation by Metal Spraying
By W. E. Ballard

Reference Blocks for Ultrasonic Inspection
IIW Commission V

High-Frequency Resistance Welding
By L. A. Johnstone, F. J. Trotter, and H. F. a'Brassard

Letters to the Editor

FATIGUE OF WELDED STRUCTURES

Fatigue Behaviour of Welded Aluminium
By J. E. Tomlinson and J. L. Wood

Fatigue of Welds in High-Strength Steels
By J. E. Stallmeyer and W. H. Munse

Engineering Aspects of Future Research
By E. M. Lewis

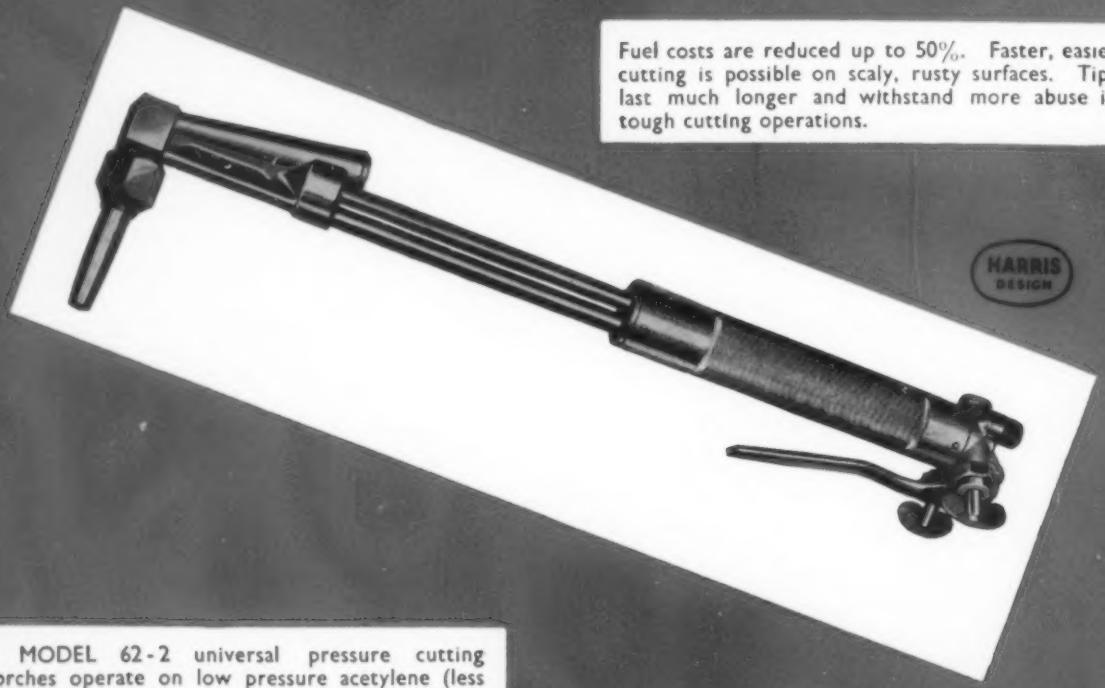
Testing Full Size Structures
By J. G. Whitman and J. F. Alder

HERE'S THE NEW

HAND CUTTING TORCH

-does the job quicker-better-cheaper

Fuel costs are reduced up to 50%. Faster, easier cutting is possible on scaly, rusty surfaces. Tips last much longer and withstand more abuse in tough cutting operations.



MODEL 62-2 universal pressure cutting torches operate on low pressure acetylene (less than 1 psi.) and also on pressure gases as supplied from generators and cylinders.

These torches enable withdrawal of all of the acetylene from cylinders. Due to the design of the injector mixture it requires only 6 oz. of acetylene for any size cutting tip. Up to 18% more acetylene can be consumed from cylinders with B.I.G. universal pressure torches.

MODEL 62-2F cutting torches are designed especially for use with propane and natural gas (pressure of ½psi. or more).

The injector in the head stabilizes the flames and insures correct mixture of the gas and oxygen, an item of great importance. Series 6290 NFF cutting tips are engineered to produce instant starting pre-heat flames, along with efficient cutting speeds.

With proper selection of tips, pressures and regulators, equal or less oxygen is consumed than with other fuels.

Hand finished -individually tested

British Industrial Gases Limited

700, GT. CAMBRIDGE RD, ENFIELD, MIDDX. Telephone: **ENfield 4022,** Telex: **22838**

Sales and Technical Assistance available in most areas

International NU-SWIFT News

No. 3

HAVE YOU MET THESE PEOPLE?

42. KUNGL. SJÖ FARTSSTYRELSEN, progressive Sweden's Ministry of Transport responsible for safety of life at sea according to the 1948 London Convention, was first maritime authority to approve Nu-Swift 30 lb. Dry Powder Extinguisher, Model 1630, for use afloat. Approval is conditional upon spare charges also being carried.

43. SAS, SCANDINAVIAN AIRLINES SYSTEM, justly renowned for service and efficiency, and 'First over the Pole', recently opened their new LONDON headquarters in fashionable Conduit Street. Nu-Swift protects the whole building, from which reservations all over the world can be made in a few minutes, before long further to be accelerated by the installation of electronic equipment.

44. Sir HUGH CASSON, famous British architect and exponent of MODERN DESIGN, is one of the many professional men whose premises are protected by Nu-Swift.

45. Rendez-vous of the cosmopolitan smart set, the famous Palace Hotel, ST. MORITZ, Switzerland, near the Cresta Run, is now protected by Nu-Swift. So are many of the vessels of the rich GREEK SHIPOWNERS who make the Palace Hotel their winter headquarters.

46. Norwegian WHALE CATCHING SHIPS each year set out from SANDEFJORD, Norway, destined for hazardous adventures in ANTARCTICA. Six or nine months later they return after incredible hardship, but often with the pockets of the crew lined with gold. Most whalers and floating whale factories are equipped with reliable Nu-Swift.

47. In lovely GREENLAND, no longer merely the home of eskimos and a colony, but part of the Kingdom of Denmark, with output from cryolite mines becoming of increasing economic importance, trading posts of the ROYAL GREENLAND TRADING CORPORATION have been equipped with Nu-Swift.

HAVE YOU BEEN TO THESE PLACES?

48. The HOME OFFICE FORENSIC LABORATORY at PRESTON, LANCS., ENGLAND, famous for its fact-searching work in many murder trials has been equipped with Nu-Swift.

49. Now also available with instructions in ARABIC, Nu-Swift extinguishers can be specified in this and any of 13 OTHER LANGUAGES at no extra charge.

50. PUNCH, the famous weekly, in recent years brightened by a face-lift, is now also, to prevent possible interruption in publication, protected by Nu-Swift. So are the giant presses in the three cities of publication of the DAILY EXPRESS, printed simultaneously every day in 4,000,000 copies, in LONDON, MANCHESTER and GLASGOW.

51. In GUATEMALA, prosperous Central American State, all the BANKS, except one, are protected by reliable Nu-Swift.

52. In the unhappy event of another global war, many CIVIL DEFENCE EXPERTS believe that the self-contained Nu-Swift Universal (Royal Navy) 2-gallon Water/CO_2 extinguishers will be of great value in dealing with the many small fires likely to flare up at some distance from a THERMO-NUCLEAR EXPLOSION at a time when public water supplies will probably be interrupted.

53. Where only a century ago, native warriors, with unexampled ferocity, fought the white man in ZULULAND, local farmers are now forming themselves into Nu-Swift fire fighting groups of five to pool their Nu-Swift fire posts and jointly combat attacks to the equally ferocious Fire Fiend. Twenty-nine such groups have so far been organised; they have proved themselves of great value in combating dangerous SUGAR CANE FIRES.

54. Through the failure of old soda acid extinguishers, CLOVER MEATS Ltd., WATERFORD, Republic of IRELAND, a firm which does a large export business, lost a contract worth £80,000. In consequence, 69 soda acid extinguishers were scrapped and instead reliable Nu-Swift were installed to the tune of £1,500.

55. The private railway coach of President KEKKONEN, the first citizen of democratic FINLAND, is now protected by effective and reliable Nu-Swift Dry Powder Extinguisher, Model 1604.

56. 'Guinness is good for you,' says the famous slogan of the GUINNESS BREWERY in Dublin, a national institution in the REPUBLIC OF IRELAND. It is now protected by Nu-Swift, and that, of course, is good for GUINNESS!

57. Founded in 1843, the NATIONAL METSOVIAN POLYTECHNIC SCHOOL in ATHENS, GREECE, the largest and most important scientific institution in South Eastern Europe and the Middle East has, after exhaustive investigation, decided to standardize on Nu-Swift extinguishers. Initial order was obtained in the teeth of keen, local, German, American and Italian competition.

58. To ensure rapid, reliable, and efficient operation at sub-zero temperatures, THE PORT OF HELSINKI AUTHORITY, FINLAND, has installed Nu-Swift Dry Powder Extinguishers for the protection of all its buildings and cranes.

59. The works of GIESEN & WOLFF LTD., NORTHAMPTON, ENGLAND, greeting card manufacturers, were recently destroyed in a 36-hour fire, fought by 80 firemen with the aid of 15 appliances. A second fire was caused in the roof of another factory nearby but was kept under control with extinguishers. Said Mr. Wood, the manager: "I would like to PRAISE THE NU-SWIFT SERVICING SCHEME. The extinguishers used by us were not of your make but your servicing kept them IN PERFECT ORDER—they saved our second factory. You can expect a large order when our new factory is built."

DISASTROUS FIRES CRIPPLE INDUSTRY,

— only reliable NU-SWIFT

is good enough for your business!

Ask for our new 94-page illustrated Catalogue: Easy-to-handle, certain-to-operate Fire Fighting Equipment

nu-swift ltd · elland · yorkshire · england

ROBEY
OF LINCOLN

introduces you to first-class work,
punctual, early delivery
and very competitive prices

Regular production includes Lloyds Class 1 Pressure Vessels.

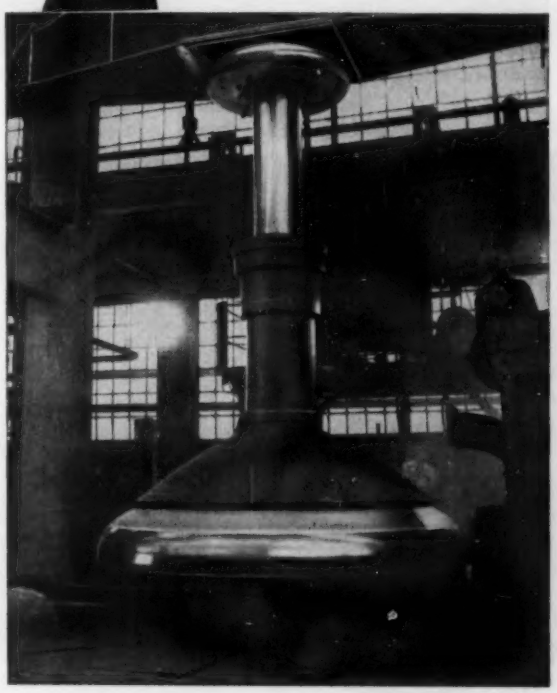
Special assignments include trunnions for the Jodrell Bank telescope; pressure vessels and special machines for nuclear power.

For WELDING

Robey & Co. Ltd. · P.O. Box 23 · Lincoln
London Office: 11 Princes St., Hanover Sq., W.1

Over a Ton of Aluminium Alloy spun to 10 ft. i/d x $1\frac{5}{8}$"

One of a number produced for pressure vessels to hold liquid air, this 10 ft. aluminium end was spun by Harveys on the Rotarpress. The 12 ft. flat discs needed for spinning these ends, which are believed to be the largest spun aluminium ends produced in this country, were formed by butt-welding two plates of aluminium alloy together.



The Rotarpress is one of the large-capacity units in Harveys Heavy Fabrication Department. It produces ends up to 15 ft. diameter and is adaptable over a wide range of knuckle radii and depths.

The contours of semi-ellipsoidal ends produced by the spinning process enable plate thickness to be reduced, and in most cases tool costs are eliminated. Enquiries are invited for ends only or for complete

FABRICATION OF PRESSURE VESSELS.

HARVEY

G. A. HARVEY & CO. (LONDON) LTD.

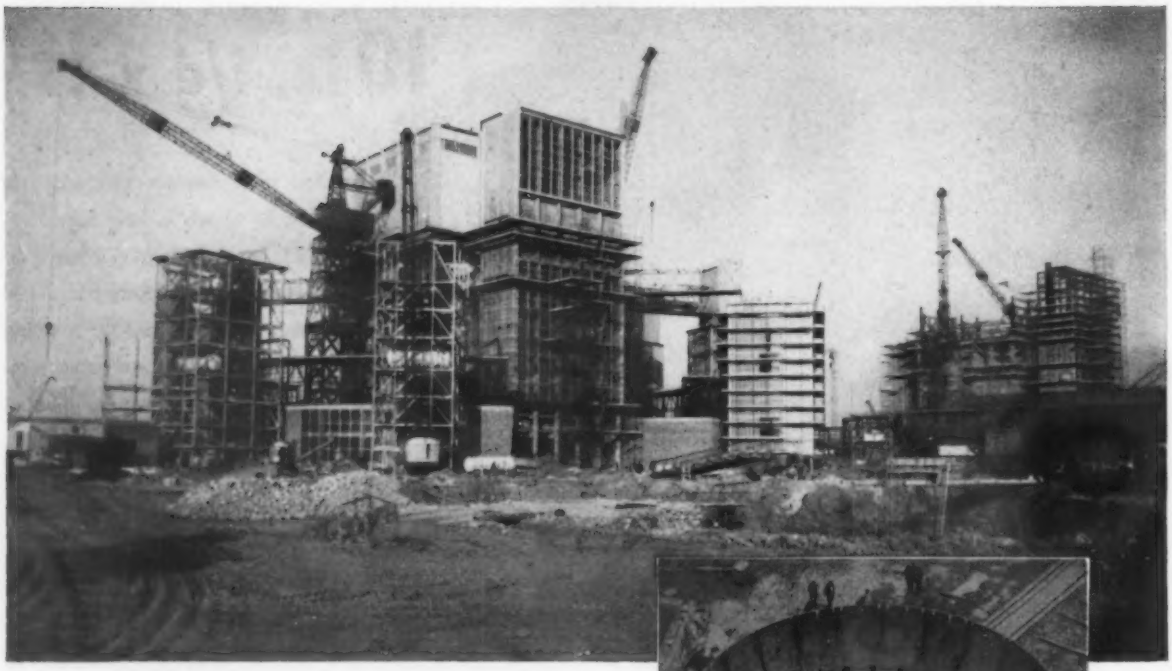
Woolwich Road, London, S.E.7. GREenwich 3232 (22 lines)

Other Harvey facilities: FABRICATIONS UP TO 120 TONS IN ONE PIECE · HEAVY MACHINING AND FITTING · HEAT TREATMENT AND RADIOGRAPHY · STEEL PLATE AND SHEET METALWORK · PERFORATED METALS · WOVEN WIRE · WIREWORK

HH/7

Pyrogas

AT BERKELEY NUCLEAR POWER STATION



Pyrogas—one of the Saturn industrial gases—and Saturn welding equipment are extensively employed in the construction of this mighty Berkeley Nuclear Power Station project. Saturn designed the pre-heating burners (with the assistance of the manufacturers, John Thompson Ltd.) . . . and supplied the burner parts for the Pyrogas/Air mixture prior to the rake burners, the hoses, regulators and the individual Torches.

Saturn also manufactured the 60 cylinder and 40 cylinder manifolds. Saturn is doing an important job at Berkeley—and on many other big industrial projects. Can we help you?

These photographs were taken at Berkeley Nuclear Power Station, which is being built for the Central Electricity Generating Board of Great Britain by A.E.I.—John Thompson Nuclear Energy Co. Ltd. In the smaller picture, the lower bowl of No. 1 Reactor vessel is being assembled in a temporary shelter, prior to being lifted into permanent foundations.

SATURN INDUSTRIAL GASES LTD

Gordon Road · Southall · Middlesex · Telephone: Southall 5611

BRANCHES: GLASGOW · ALDRIDGE · MANCHESTER · SHEFFIELD · LYMINGTON · SUNDERLAND · THORNABY-ON-TEES

SIG. 6

Welding Copper

Really up-to-date welders tend nowadays to prefer shielded-arc techniques for joining copper. They know that by using filler alloys specially developed by I.C.I. for the purpose, sound welds can now be made in all grades of copper. Alloying elements are kept to a minimum so that the properties of the welds are similar to the parent metal. You must add sufficient filler to ensure that the deoxidising elements do their job properly.

Choose your filler according to the job in hand and the welding method best suited to it—

'ARGOFIL' for welding phosphorus deoxidised copper by tungsten-arc or metal-arc, argon shielded.

'NITROFIL' for welding phosphorus deoxidised copper by tungsten-arc, nitrogen shielded

'BOROFIL' for welding tough pitch copper where high electrical conductivity must be maintained—tungsten-arc or metal-arc, argon shielded.

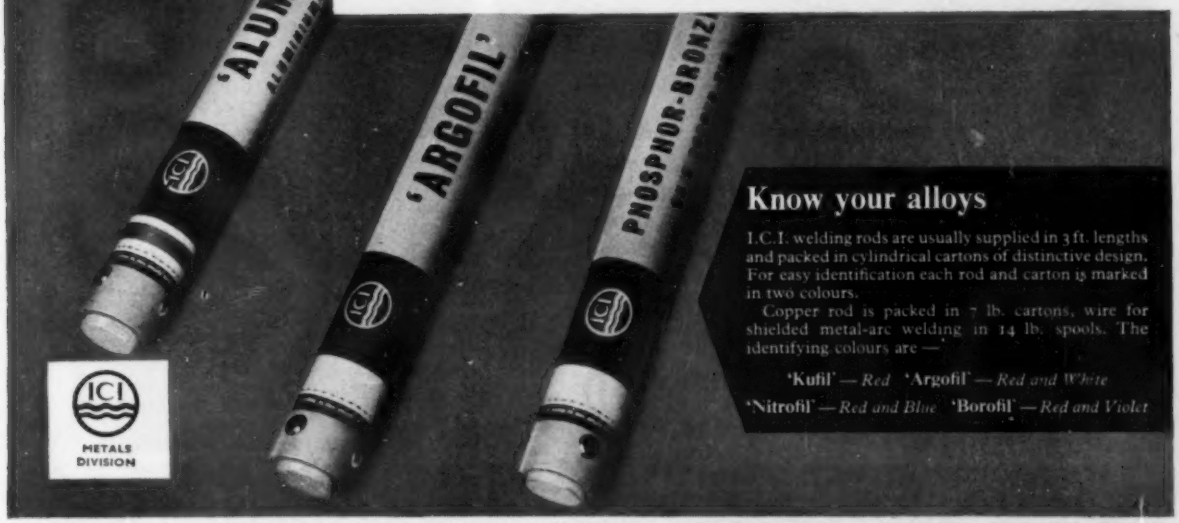
*Reminder! As the Commonwealth's largest producer of wrought non-ferrous metals, I.C.I. Metals Division has built up exceptional knowledge of welding techniques. We specialise in wrought metals and alloys particularly suitable for welding and brazing—and in materials for carrying out the various welding techniques. We are always glad to help clients in selecting the most appropriate materials and processes. Please send now for our special booklet 'I.C.I. Welding Rods and Brazing Materials'.

I.C.I. Copper Welding Rods

Alloy	Size range	Process	Approx. melting point (°C.)
'Kufil'	1/16 in. to ¼ in. diameter in straight lengths Down to 20 s.w.g. (0.036 in.) in coil	Oxy-acetylene (Boric acid type flux)	1073-1078
'Argofil'	1/16 in. to ¼ in. diameter in straight lengths Down to 20 s.w.g. (0.036 in.) in coil Also on spools for I.G.S.M.A. welding	Argon arc and I.G.S.M.A.	1083
'Nitrofil'	As above	Nitrogen arc	1083
'Borofil'	As above	Argon arc and I.G.S.M.A.	1083

Quick delivery

We make a very large range of welding and brazing rods and orders for many standard lines can be filled from stock. Your nearest I.C.I. SALES OFFICE *will ensure that you get prompt delivery of any materials ordered.*



Know your alloys

I.C.I. welding rods are usually supplied in 3 ft. lengths and packed in cylindrical cartons of distinctive design. For easy identification each rod and carton is marked in two colours.

Copper rod is packed in 7 lb. cartons, wire for shielded metal-arc welding in 14 lb. spools. The identifying colours are —

'Kufil' — *Red* **'Argofil'** — *Red and White*

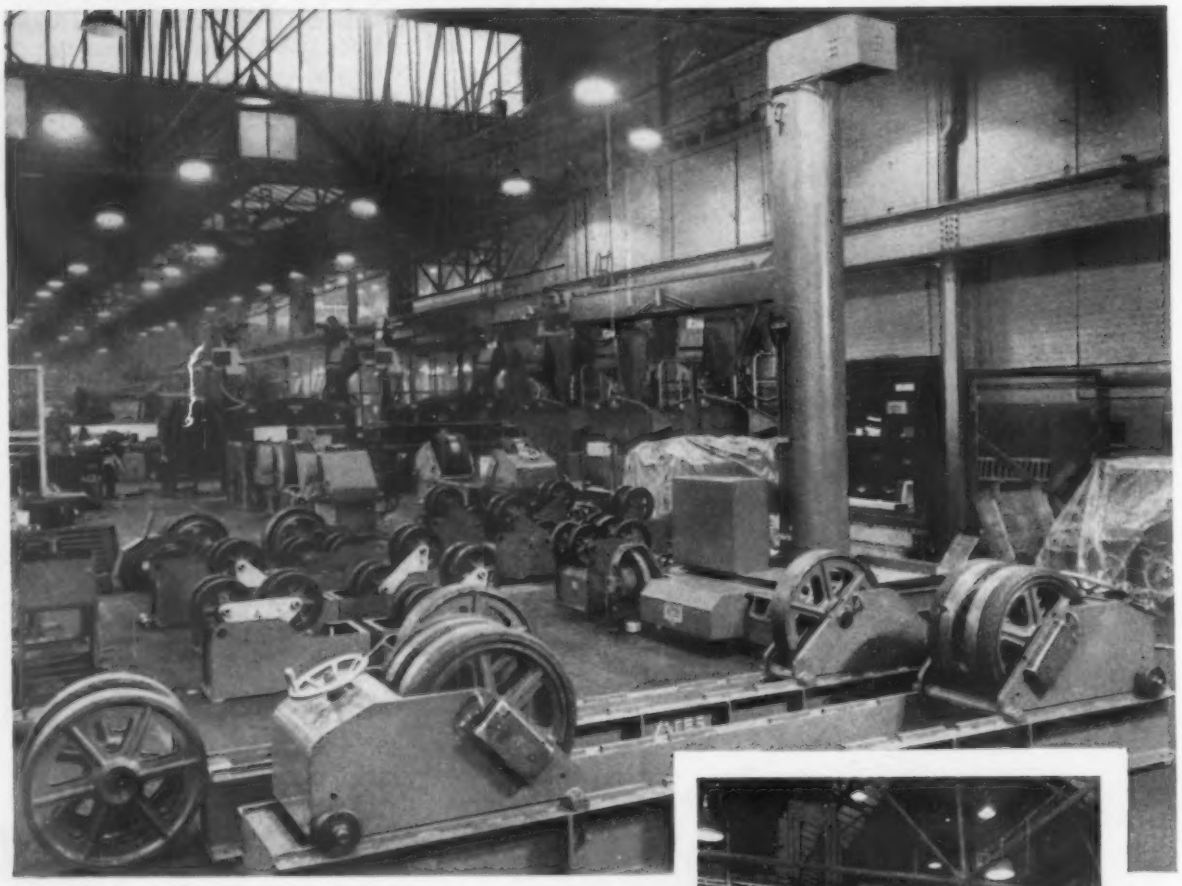
'Nitrofil' — *Red and Blue* **'Borofil'** — *Red and Violet*

IMPERIAL CHEMICAL INDUSTRIES LIMITED, LONDON, S.W.1.

M. 23

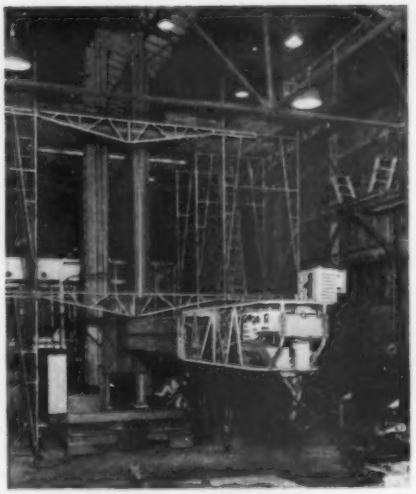
They're busy at Bedewell!

(THE HOME OF YATES PLANT)



General view of one of the Bedewell shops.

These photos were taken recently at Bedewell Works, Hebburn-on-Tyne, the Baker Perkins Group factory where Yates Plant equipment is made. Here, a full range of patented welding manipulative equipment is manufactured, all with the latest exclusive refinements developed by Yates Plant and all built to the highest engineering standards.



Erecting a "mammoth" 45 ft. column and boom. This unit has been supplied for work in atomic power station construction.

YATES PLANT LTD

WHIDBORNE STREET, LONDON W C 1

Telephone: TERminus 0568, 0842 Cables: Manipul, London

A MEMBER OF THE BAKER PERKINS GROUP

Electronic Control

from simple timing relays

to complete process control

systems

AEI specialists will advise you on...

- precision control of motor drives
- voltage control
- photo-electric process control
- control of resistance welding
- remote control of cranes
- machine-tool control

Please write for technical data and a copy of our brochure, 'Electronics in Industry.' Give us details of your control problems, and we shall be glad to assist you.

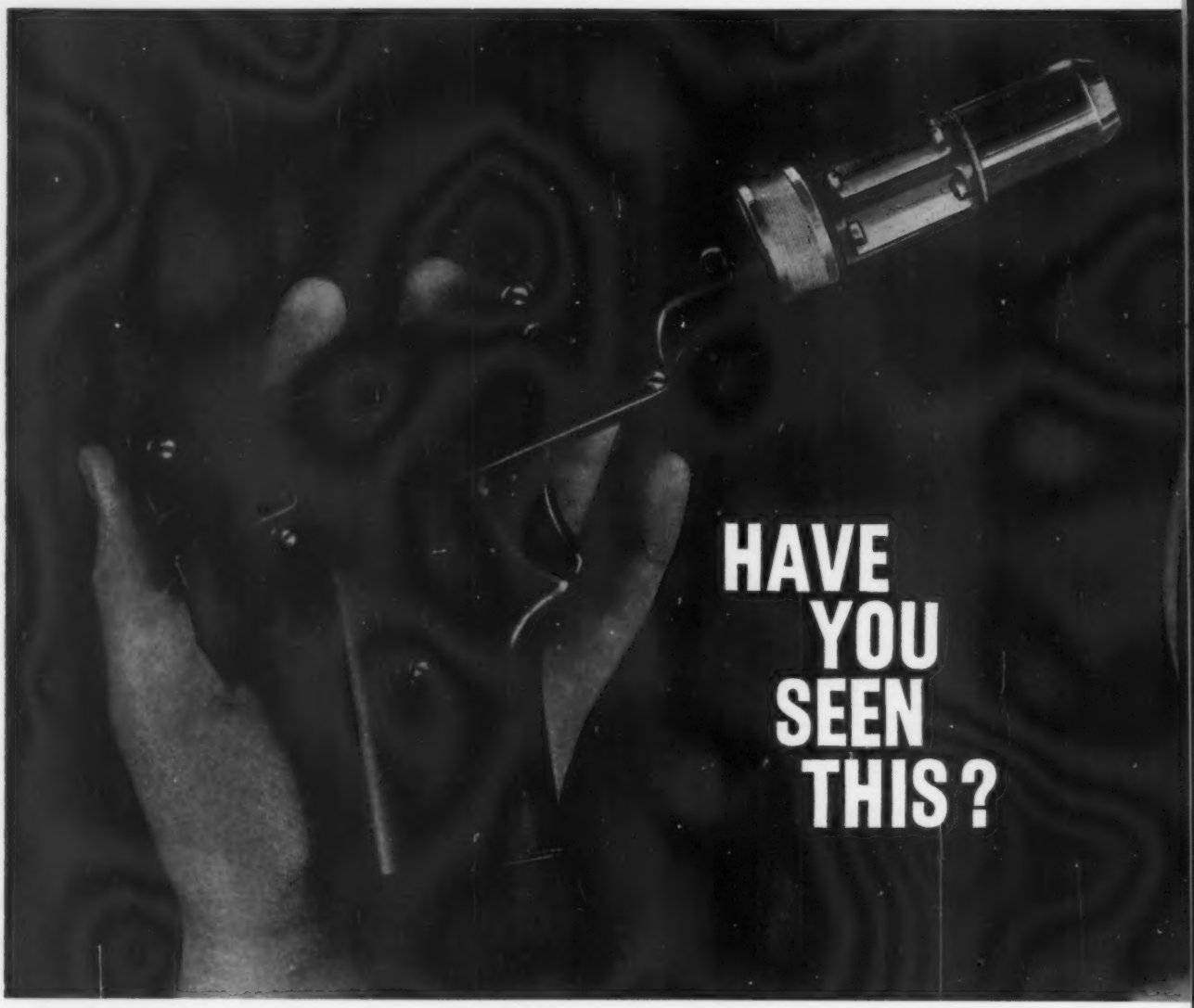
AEI

Associated Electrical Industries Limited

Electronic Apparatus Division

NEW PARKS, LEICESTER, ENGLAND

A3163



RUBERY OWEN are sole licensees in Britain for the manufacture of West-ing-arc welding equipment with which the Westinghouse Electric Corporation of Buffalo, New York, has galvanised the automobile, shipbuilding and general engineering industries of the U.S.A.
This system of gas-shielded metal-arc consumable electrode welding is now known in Britain as ROWEN-ARC. Rubery Owen are also sole distributors in the U.K. of West-ing-arc welding equipment.
Rowen-Arc has many advantages over conventional methods. It permits welding at twice the speed in steel . . . up to ten times the speed in aluminium. Production costs have been cut enormously in many industries. In proven cases users have recovered the entire cost of outlay in a few weeks of operation.

ROWEN-ARC New welding technique from America!
Gas-shielded metal-arc consumable-electrode welding

Rowen-Arc Technical Department is solving many customer welding problems right now — it can do the same for you!

ROWEN-ARC
DIVISION OF RUBERY OWEN AND CO. LTD.
LONGFORD WORKS, BLACKHORSE ROAD
LONGFORD, COVENTRY. TEL: BEDWORTH 2179
A member of the Owen Organisation

ROWEN-ARC RA ENGLAND

1. SA-120 SERIES
Lightweight air-cooled Rowen-Gun with self-contained automatic wire drive, and Control Monitor. For light duty welding of aluminium and steel up to 200 amps.

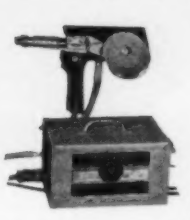
2. SA-1 SERIES
Medium water cooled Rowen-Gun. Independent automatic wire feed on Control unit. For heavy duty welding of mild steel up to 500 amps.

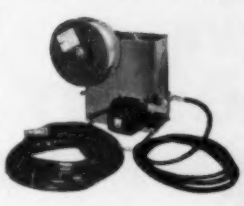
3. PORT-ARC SERIES
Self-contained mobile unit comprising 500 amp welder. Control unit with automatic wire feed, portable guns, water circulating system and provision for gas bottles.

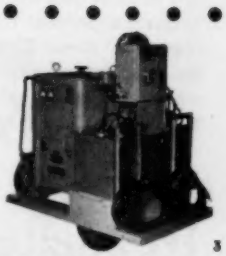
4. SA-40 SERIES
Heavy duty welding head, control monitor with automatic wire feed, operator's remote control station. For high production automatic welding using CO_2.

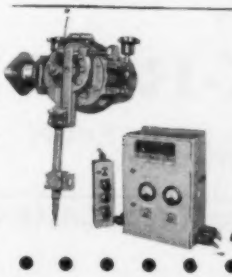
5. POWER PACKS
Constant potential rectifier type welders 200A and 500A.

6. DYNAMIC REACTOR
Used in circuit, permits welding in all positions with negligible spatter. Greatly extends welding range on thin gauge metals.


1


2


3


4

5

6

To feed London Airport

The new twin pipeline
for Shell-Mex and B.P. Ltd.
runs from Walton-on-Thames
to London Airport
under several main roads,
under the Thames at Sunbury,
under two railway lines,
and under the Airport runways.
Yet, apart from closing the river
at Sunbury for a few hours
so divers could lay the pipe
in a trench on the river bed,
and operating short periods of
one-way traffic along some roads,
the contractors did the job with
little disturbance to the public.
Construction work was by
William Press & Sons Ltd.
Inspection Services Ltd. were appointed
to carry out weld supervision
and radiographic inspection of welds.
Welding had to be done at
several points simultaneously,
points many miles apart,
but by using mobile vans
equipped to process and inspect
radiographs on the spot,
Inspection Services were able to
keep right up with the welders.
Often, trenches were filled in
and normal traffic resumed
within an hour of welding.
For proof of perfect welding,
Inspection Services relied on
'*Industrex*' *X-ray Film Type D*
the fast, high-contrast film
which is the preferred material
for all weld inspection work.

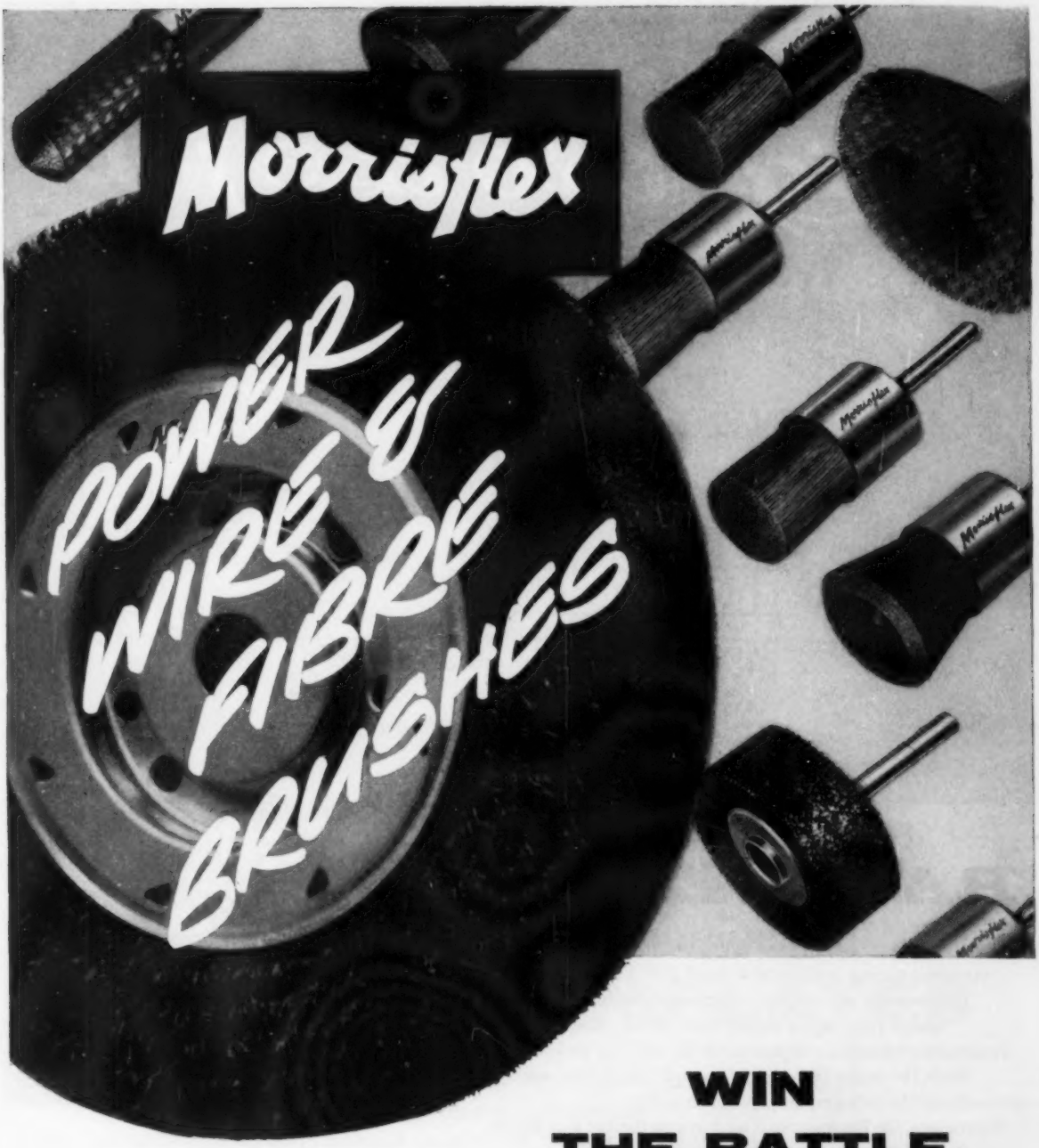
Crown Copyright reserved

Kodak

INDUSTRIAL X-RAY FILMS

— the preferred films for weld inspection

KODAK LIMITED, INDUSTRIAL SALES DIVISION, KODAK HOUSE, KINGSWAY, LONDON, W.C.2



WIN THE BATTLE OF THE BURR

B. O. MORRIS LTD. · MORRISFLEX WORKS, BRITON ROAD · COVENTRY

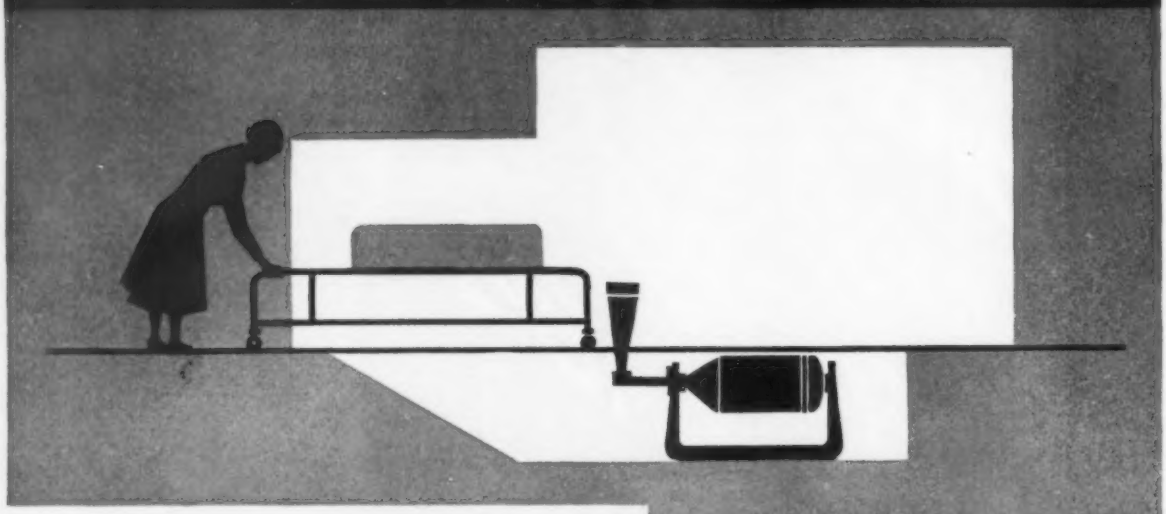
Telephone : 53333 (PBX) Telegrams : MORISFLEX, COVENTRY

PRODUCT OF THE Morrisflex GROUP

Right to the job

at the

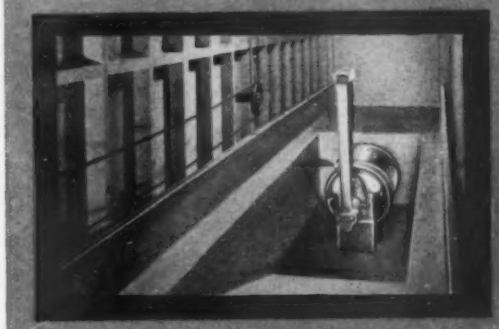
ROYAL ORDNANCE FACTORY PATRICROFT



The LIGHTWEIGHT

RAYMAX 150

Here, five Raymax 150 units make an impressive and economic testing installation at the R.O.F. Patricroft. Components are tested in narrow space-saving leadply tunnels right on the factory floor. When examining longitudinal joints the component on the trolley is moved down the tunnel by means of a simple chain drive worked externally by the radiographer. As shown in the illustrations, the Raymax 150 is sunk in a pit thereby simplifying the protective measures necessary as the beam is always directed upwards against the roof of the tunnel.



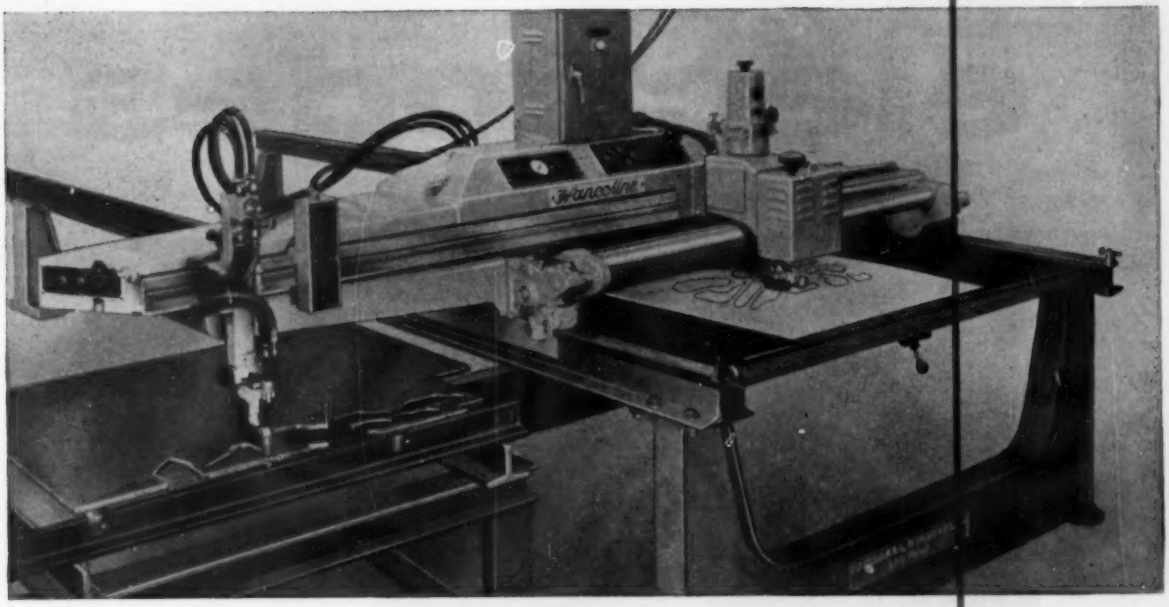
In this installation the use of leadply tunnels only 4 ft. wide, instead of larger radiographic rooms, enables a considerable saving to be achieved in costly protective materials, in floor space and in time as the components do not have to be taken away from the shop floor. The gas-insulated Raymax 150 weighs only half conventional oil-insulated units. It gives high radiographic output, and its special design eliminates high voltage cables, rectifying valves and associated filament transformers.

Write for publication SP.7176/1
to your local AEI office or direct to:

Associated Electrical Industries Limited

INSTRUMENTATION DIVISION – Scientific Apparatus and X-Ray Department
132/153 Long Acre, London W.C.2

Consider this point...



NEW HANCOLINE

OXYGEN CUTTING MACHINE

NEEDS NO TEMPLATES

The new electronic Hancoline brings absolute simplicity to oxygen profiling. It traces from a simple pencil line drawing — automatically. No templates whatever are needed. Think what a saving that means in storage space and how much production costs can be reduced! The Hancoline cuts time and labour while turning out a clean, precision job — every time.

- ★ Cut width compensation on tracer head.
- ★ Fitted with Hancock roller drive — no physical contact between tracer and drawing.

The Hancoline is available in four cutting widths. The largest size can profile plates up to 10 feet wide in one setting.

Write for details

HANCOCK & CO. (Engineers) LTD

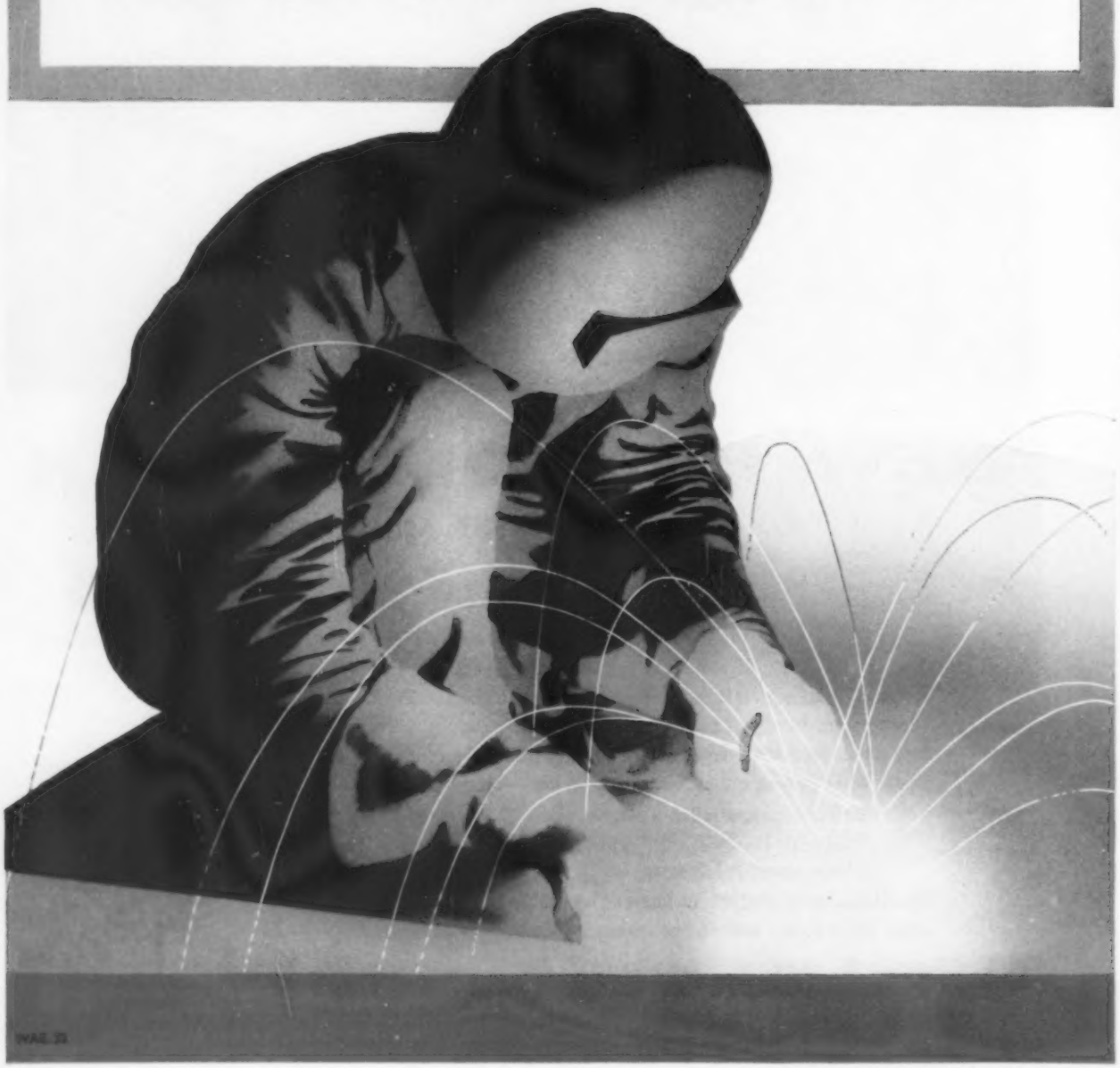
1st The first name in OXYGEN CUTTING — HANCOCK CUTTING MACHINES

PROGRESS WAY · CROYDON, SURREY · Telephone: Croydon 1908 · Cables: Hanco Croydon

TIB.173

'ENGLISH ELECTRIC'

electrodes



EACH ELECTRODE in this range has been individually developed under stringent laboratory control to give the best results on the metal for which it was designed.

FOR EASE IN WELDING REMEMBER THEM BY NAME

Choose the special one made for your exact purpose—

FOR WELDING MILD STEEL

ENROX —general purpose electrode.
WELDEES —for easy welding of mild steel.
VOHEES —for all positions, particularly vertical and overhead.
SPEEDEES —for very rapid downhand welding.
VERTEES —for vertical and overhead welds.
DEEPEES —for deep penetration.
PRESSUREES —for deep groove welding.
PRESSUREES IP.I —for fast and easy deep groove welding.

FOR WELDING SPECIAL STEELS

HERMEES —for fast welding of high tensile steels.
HERCULEES 35 —Low hydrogen electrode for tensile strength up to 35 tons P.S.I.
LOWHEES —General purpose low hydrogen electrodes.
STAINEES M —for 18/8 stainless steel.
STAINEES N —for 18/8 stabilised stainless steel.
PYRISTEES 1 —for creep resisting steels operating at temperatures up to 950°F.
PYRISTEES 2 —for creep resisting steels operating at temperatures up to 1050°F.

FOR WELDING CAST IRON

CASTEES N —giving an easily machined weld.
CASTEES SG —for spheroidal graphite cast iron.

FOR HARD SURFACING

HARDEES —in grades from 250 to 650 V.P.H.
MANGANEES —for manganese steel.

FOR GOUGING AND PIERCING

GROOVEES —suitable for all metals.

FOR FILLING

FILLEREES—specially for filling cavities in steel castings.

All are quality controlled by welding tests on every batch made.

WRITE NOW *for detailed work chart which gives the correct grade of electrode for every application*

'ENGLISH ELECTRIC'

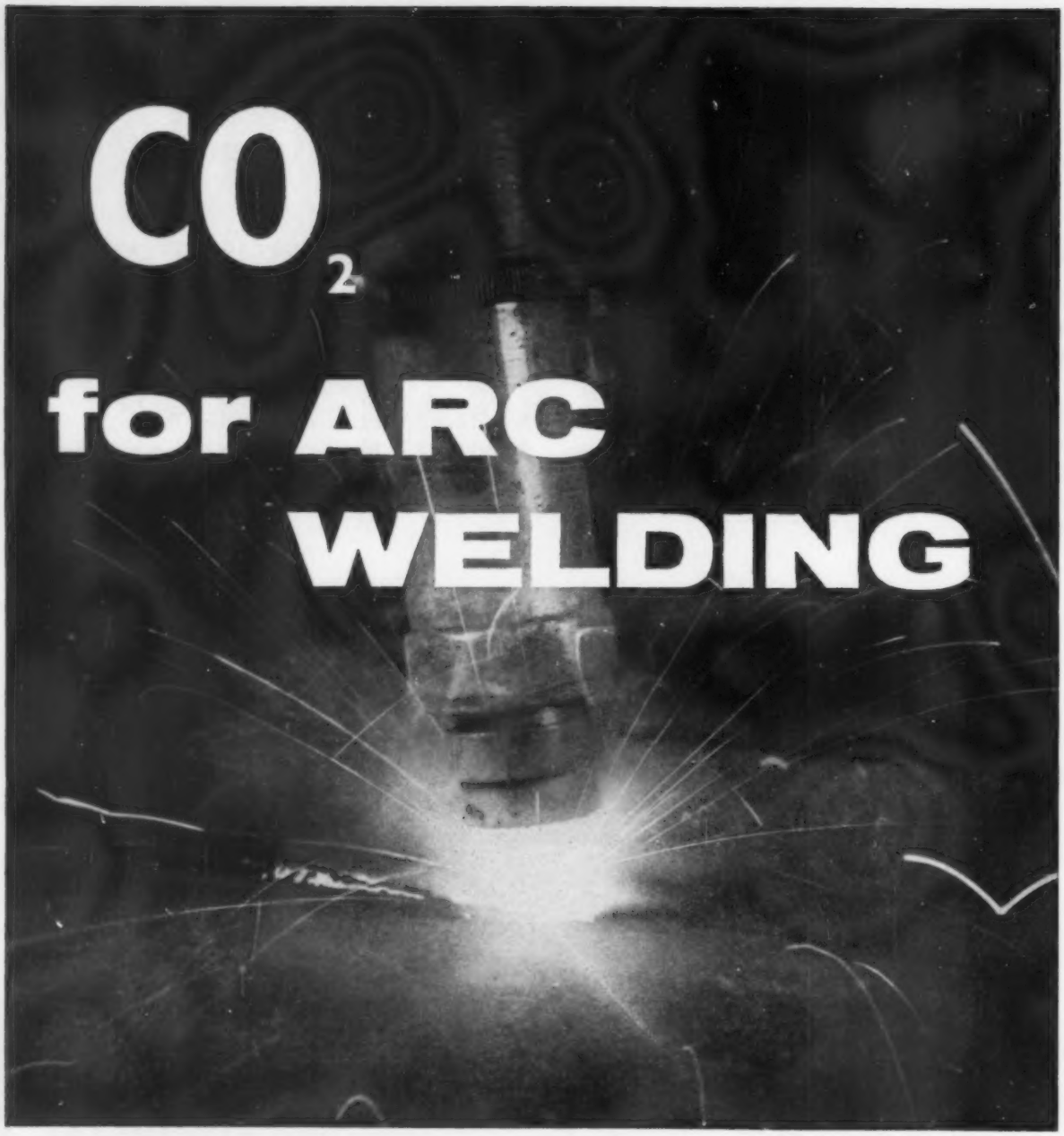
welding electrodes and equipment

THE ENGLISH ELECTRIC COMPANY LIMITED

MARCONI HOUSE, STRAND, LONDON, W.C.2

Welding Equipment Division,
East Lancashire Road, Liverpool 10.
Telephone: Aintree 3641

Welding Electrode Division,
Clayton-le-Moors, Accrington.
Telephone: Accrington 3241



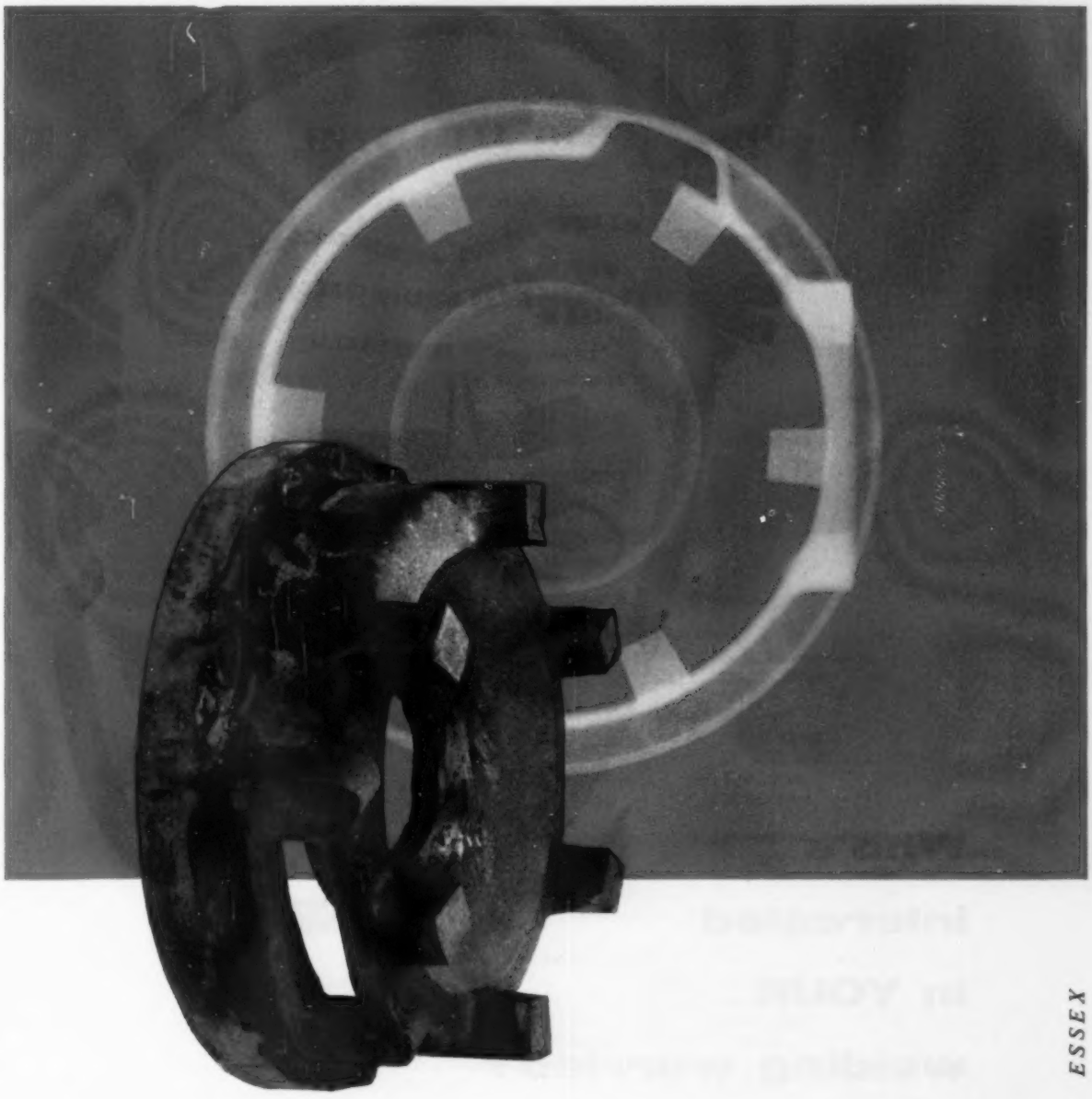
DCL

SUPPLY
Bulk Liquid and Cylinders

CARBON DIOXIDE

STORAGE
Installation and Maintenance

THE DISTILLERS COMPANY LIMITED · CHEMICAL DIVISION
Carbon Dioxide Department · Devonshire House · Piccadilly · London · W1 · Mayfair 8867



for fine grain and better definition—

Outstanding for its exceptionally fine grain, ILFORD CX is a high-contrast film of medium speed. It can be used with or without lead screens, for industrial radiography up to two million volts, and for gamma radiography. It is ideal for those applications where superior definition is preferred to speed, particularly for the examination of light metal and steel castings, and for the inspection of welds. Recommended developer is Phenisol—based on Phenidone, an Ilford discovery—which gives high effective film speed and promotes contrast, without accentuating grain.

The name PHENIDONE is a registered trade mark

ILFORD *CX* industrial X-ray film

ILFORD LIMITED · ILFORD · ESSEX

Who's interested in YOUR welding worries?

MAPEL is. MAPEL knows *all* about welding supervision and inspection . . . can supply skilled advice on the best techniques, procedure and practice . . . can train your welders to high standards . . . can test welds speedily by visual, radiographic and the latest ultrasonic methods. *It saves you worry and money!*

Call in MAPEL for Welding Inspection — for Cathodic Protection and Leak Detection, too.

METAL & PIPELINE ENDURANCE LTD
30 London Road, Woolmer Green, Hertfordshire
Telephone: Knebworth 3083. Telegrams: Metaldure, Knebworth

MAPEL

Other Offices at London, Newcastle-upon-Tyne and Glasgow

WORLD-WIDE SERVICE

INSTITUTE OF WELDING

54 Princes Gate, London, S.W.7

COUNCIL AND OFFICERS

PRESIDENT
E. Seymour-Semper

VICE-PRESIDENTS
W. Barr, O.B.E. — E. Fuchs — G. Roberts

PAST-PRESIDENT
J. Strong

HONORARY TREASURER
W. E. Harriss

Chairman of Executive Committee: R. E. G. Weddell

Representatives of Industrial Corporate Members

E. F. Burford, M.B.E.	N. L. G. Lingwood	E. S. Waddington
C. Humphrey Davy	J. A. McWilliam, T.D.	Dr. R. Weck

Representatives of Fellows, Members, and Associate Members

D. J. W. Boag	J. A. Dorrat	Dr. N. Gross
V. W. Clack	E. Flintham	D. B. Kimber, O.B.E.
F. Clark, M.B.E.	E. P. S. Gardner	T. McIver
D. C. C. Dixon	S. H. Griffiths	H. Martin

Representative of Companions
J. Hooper

Representative of Associates
A. Evitts

Chairman of B.W.R.A. Council
A. Robert Jenkins, J.P.

Chairmen of Standing Committees

Education Committee	Prof. J. G. Ball
Finance Committee	W. E. Harriss
Membership Committee	R. G. Braithwaite
Programme and Publications Committee	J. F. Lancaster
School of Welding Technology Committee	E. Fuchs
Technical Committee	J. A. Dorrat

Representatives of Branches

Birmingham	W. R. Harper	Preston	F. Pilling
East Midlands		Sheffield	W. A. Jenkins, J.P.
East of Scotland	J. F. Wheeldon	Southern Counties	J. H. Gillespie
Eastern Counties	J. Edwards	South London	P. J. E. Heath
Leeds	E. Rose	South Wales	I. B. Ford
Liverpool	G. A. O. Pridgeon	South Western	A. J. Francis
Manchester	J. M. Whitworth	West of Scotland	J. E. Roberts
North Eastern (Tees-side)	J. W. Jackson	Wolverhampton	M. R. Liddiatt
North Eastern (Tyneside)	R. A. Exton		
North London	C. R. Thatcher		
	L. C. Percival		

SECRETARY
G. Parsloe

new Lightweight Saffire has many advantages

* *Light to handle*
* *Beautifully balanced*
* *Designed by experts*
* *Precision made*
* *Greater flame stability*
* *Surer resistance to backfire*

BRITISH OXYGEN GASES LIMITED

Industrial Division, Spencer House,
27 St. James's Place, London S.W.1

A BOC Company

BRITISH WELDING RESEARCH ASSOCIATION

19 Fitzroy Square, London, W.1

COUNCIL AND RESEARCH BOARD

PRESIDENT

SIR CHARLES S. LILLICRAP, K.C.B., M.B.E.

CHAIRMAN OF COUNCIL

A. ROBERT JENKINS, J.P.

HONORARY TREASURER

W. E. HARRISS

MEMBERS OF COUNCIL

SIR DONALD BAILEY, O.B.E., J.P.
PROF. J. F. BAKER, O.B.E., F.R.S.
DR. R. BEECHING
D. J. W. BOAG
J. BROWN
DR. T. W. F. BROWN, C.B.E.
C. HUMPHREY DAVY
C. H. FLURSCHEIM
T. M. HERBERT
E. J. HILL
F. C. S. L. LEWIN-HARRIS
H. PEARSON LOBNITZ
SIR ANDREW MCCANCE, F.R.S.
RICHARD MILES
J. MITCHELL, C.B.E.
PROF. SIR ALFRED PUGSLEY, O.B.E., F.R.S.
L. ROTHERHAM
E. SEYMOUR-SEMPER
R. B. SHEPHEARD, C.B.E.
C. M. SPIELMAN, O.B.E., M.C.
T. STEVENSON
J. H. N. THOMPSON, M.C.
LT.-COL. J. F. TODHUNTER
W. T. TOWLER, J.P.
DR. M. A. VERNON
DR. E. G. WEST
J. M. WILLEY

RESEARCH BOARD

DR. E. G. WEST (*Chairman*)
DR. N. P. ALLEN, F.R.S.
PROF. G. WESLEY AUSTIN, O.B.E.
PROF. J. G. BALL
W. BARR, O.B.E.
DR. L. E. BENSON
DR. J. S. BLAIR
DR. N. BOOTH
E. FUCHS
E. P. S. GARDNER
A. H. GOODGER
DR. NICOL GROSS
DR. H. K. HARDY
DR. H. HARRIS
A. ROBERT JENKINS, J.P.
SIR CHARLES LILLICRAP, K.C.B., M.B.E., D.SC.
DR. N. J. L. MEGSON
DR. W. I. PUMPHREY
DR. L. REEVE
G. ROBERTS
PROF. E. C. ROLLASON
DR. H. SUTTON, C.B.E.
J. TURNBULL
DR. J. H. WEAVING

DIRECTOR OF RESEARCH

DR. RICHARD WECK

SECRETARY

A. O'NEILL

NEW

BALTOSPOT G 300 D

NEW - Insulation by gas
- Complete protection against overload and over-heating
- Protection against shock by protective cradle or rubber end rings
- LIGHT weight saves LABOUR

On site and in the works, the BALTOSPOT G 300 D supplies the HARD X-Rays necessary for the control of heavy and medium steel plates on fine grain films
Maximum kVP 300
X-RAY Tankhead weight 142 lb - 64 kg
Protective end rings 6 lb - 2.5 kg or
Protective cradle 29 lb - 13 kg.
Other units available from 50 to 200 kV

Available in the U. K. from
Messrs. PANTAK LIMITED
Vale Road
WINDSOR - Berks

Manufactured by :
USINES BALTEAU, S. A.

Balteau

Rue de Serbie
LIEGE - Belgium

3-RX1-59

BRITISH WELDING JOURNAL

OFFICIAL JOURNAL OF THE INSTITUTE OF WELDING AND THE BRITISH WELDING RESEARCH ASSOCIATION

Incorporating the *TRANSACTIONS* of the Institute and *WELDING RESEARCH*

CONTENTS

INSTITUTE OF WELDING

223 **Reclamation by Metal Spraying**
By W. E. Ballard

238 **Performance Record of the Thermatool High-Frequency Resistance Welding Process**
By L. A. Johnstone, F. J. Trotter, and H. F. a'Brassard

237, 249 **Letters to the Editor**

INTERNATIONAL INSTITUTE OF WELDING

230 **Use of Reference Blocks for Checking Ultrasonic Inspection Apparatus** *Commission V*

BRITISH WELDING RESEARCH ASSOCIATION

Symposium on Fatigue of Welded Structures

250 **Factors Influencing the Fatigue Behaviour of Welded Aluminium**
By J. E. Tomlinson and J. L. Wood

265 **Future Research—Engineering Aspects**
By E. M. Lewis

272 **Programmed Fatigue Testing of Full Sized Welded Steel Structural Assemblies**
By J. G. Whitman and J. F. Alder

281 **Fatigue of Welded Joints in High-Strength Steels**
By J. E. Stallmeyer and W. H. Munse

288 NEWS AND ANNOUNCEMENTS

294 CURRENT WELDING LITERATURE

APRIL 1960
Volume 7 Number 4

Subscriptions
Members free:
Extra copies at 7*s.* 6*d.* each
Non-Members:
£5 per annum
Single copies 10*s.* each

Published Monthly

Editor-in-Chief: G. PARSLOE, M.A.
54 Princes Gate, London, S.W.7
(Knightsbridge 8556)

Executive Editor:
C. ROWLAND HARMAN, B.Sc. (Eng.)
Editech
77a Chertsey Road
Woking, Surrey
(Woking 5838)

Advertisement Manager:
G. S. HARTLEY,
54 Princes Gate, London, S.W.7.
(Knightsbridge 8556).

Note: Editorial contents copyright. The Institute of Welding and the British Welding Research Association do not hold themselves responsible for statements made or opinions expressed in articles appearing in this Journal.

The Institute of Welding 54 Princes Gate, London S.W.7

British Welding Research Association 19 Fitzroy Square, London W.1

On with a Norton BDA wheel–

off with the weld bead!

This 9" x ¼" x ¼" depressed centre wheel is a Norton A241-QBDA reinforced resinoid wheel. It is mounted and ready now to cut into its work with speed *and* safety, because it is doubly reinforced with a strong integral fabric and a tough nylon safety web.

They're versatile, these Norton BDA Reinforced Wheels. Use them for cleaning up, bevelling, cutting down, and smoothing (for cutting-off specify the thinner BD type). Roughing and finishing, tough Norton Reinforced Wheels will do a sturdy job—and do it with the utmost speed and economy.

In the Norton range of wheels—over 100,000 sizes, shapes and specifications—there is one that is exactly right for your job. Let your Norton or Alfred Herbert representative help you select it, and if you want it for weld grinding, cleaning up and the multitude of jobs you do with your portable right-angle grinder, it will probably be a Norton BDA or BD reinforced resinoid wheel.

Get through more work with Norton Abrasives

*NORTON ABRASIVES

NORTON GRINDING WHEEL COMPANY LIMITED

Welwyn Garden City, Herts. *Telephone: Welwyn Garden 3484 (15 lines)*

Enquiries also to: **ALFRED HERBERT LIMITED, Coventry** · Telephone: Coventry 89221

NORTON and BEHR-MANNING factories also in Argentina, Australia, Brazil, Canada, France, Germany, Italy, Northern Ireland, South Africa and U.S.A.

**Regd. Trade Mark of Norton Grinding Wheel Co. Ltd.*

N.G.W. BDA. 158

Welding
TECHNOLOGY

Reclamation by Metal Spraying

By W. E. Ballard, F.R.I.C., F.I.M.

The paper reviews the development of the metal spraying process, briefly describes its operation, and gives examples of applications in the reclamation of shafts and flat surfaces.

The properties of the sprayed coatings are considered and the results of experimental work are quoted.

The application of the process to hard facing and to the deposition of ceramics is also mentioned.

As an industrial process, metal spraying is comparatively new, for it is not fifty years since the first patent was published, and the process had very little commercial significance until the nineteen-thirties. It then became of considerable value for applying protective coatings to steel, and very large contracts have been and are being carried out: the new Forth Bridge, which will be one of the world's major engineering works, is to be sprayed with zinc. For the production of protective coatings the process has been mechanized to a considerable extent, and it is quite impossible to give even a general picture of applications within the compass of a short paper. This paper is therefore confined to a résumé of the reclamation of worn machine parts and of some recent developments of the spraying technique.

Early Developments

It is now impossible to trace who was the first operator of the process to apply a sprayed deposit for the repair of a machine part, but it is very likely that the experiment was made in Germany during the first world war in an endeavour to repair worn armature shafts without the need to remove the windings. In any event a certain success was obtained, and gradually the use of the process for the purpose extended, and in the thirties a commercial sales drive in America caused increased interest.

In Britain the adoption of the method was very slow because of the fear that the methods of preparation for the sprayed deposit would cause fatigue failures. As a metallurgist, and being familiar with the dangers of the notch effect, the author counselled the greatest caution in the use of the process on highly stressed parts. In America, where perhaps engineers are more adventurous, spraying was being used more and more for repair work, and it was difficult to obtain news of failures. As a result, development in Great Britain started first with the tentative repair of shafts worn in ball race housings and then extended to the repair of shafts, many of considerable size. This system was adopted by some large manufacturers of machine tools with unqualified success, and by 1939 its excellence for selected work was established. The shortage of spares for machines generally, and some types of engines in particular, made it an essential technique in the war effort. There have been failures of course, mostly due to faulty preparation or bad machining, but from thousands of shafts so treated, the author has seen only two cases of fracture which might have been due to fatigue.

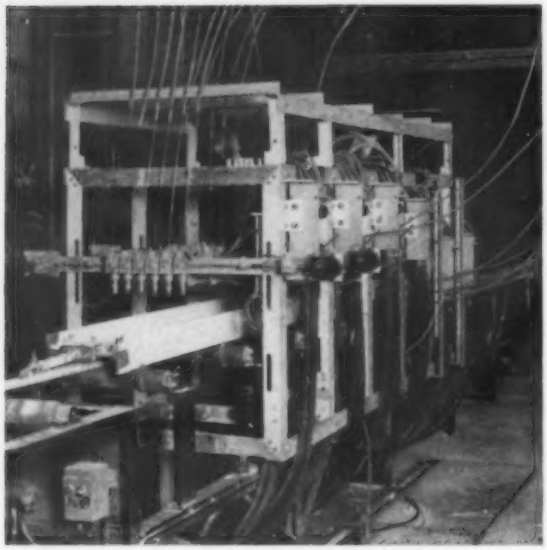
It is important to realize that before the 1939 war it was not easy to obtain scientific data on fatigue and wear owing to the shortage of complicated testing equipment. The process developed therefore by practical trial rather than by scientific tests.

Equipment

Although, as with the wire system, the powder process of metal spraying is used for anti-corrosive

This paper was presented in 1959 to the Netherlands Advisory Bureau for Gas Welding and Allied Processes, and is reproduced from the journal *Lastechniek* (1959, Nov., No. 11) with the kind permission of the publishers and of the Advisory Bureau.

Mr. Ballard is Managing Director of Metallisation Ltd.



1—*Mechanized spraying of beam profiles*

coatings, reclamation work is almost always carried out with wire as the raw material. The tools used are often known as pistols and the hand tool is usually of the type using an oxy-gas flame for melting. The wire feed is powered by an air wheel, integral with the case. Modern pistols will accommodate wires of 4 mm dia., and the wire speed is controlled by an internal governor sometimes making use of magnets. When heavy deposits are required the wire feed is powered by an external motor connected by a flexible shaft, or the motor and spraying head are mounted together on a plate fixed to the slide rest of a lathe. The largest diameters of wire are about 5 mm. Further increases in size tend to produce uneven melting and instability even with high air pressures.

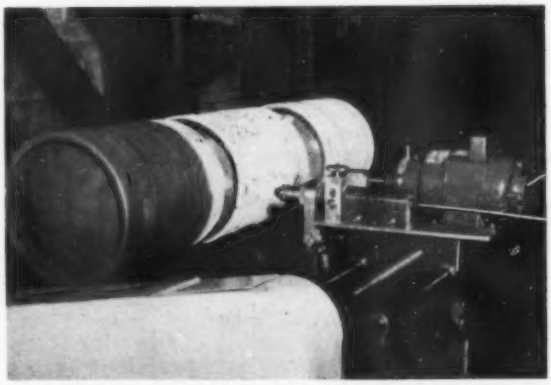
In Europe an electric arc pistol is used, the arc being struck between the tips of two advancing wires. It is better to use direct current, and the tools are quite frequently fitted with high-frequency ionizers to initiate and stabilize the arc. The advantages of the electrical system are high speed and cheapness. The disadvantages are the high capital cost of transformers and rectifiers, high oxidation, and less control of the texture of the deposit. In Great Britain, America, and France very little work is done with arc pistols although it may well be that with the development of the constricted arc, the position may be changed in a few years time.

Formation of Deposit

In engineering work it must be remembered that the major cost of the process is not the spraying but the preparation and the final grinding or machining. It is more important, therefore, to have a sound deposit than one that is a little cheaper but not technically so good.

Before going further into the details of spraying as an engineering tool it seems to be desirable to consider the nature of the deposit and this is best done by following its mode of formation.

In wire spraying, metal is torn from the rod as it melts as a thin film, and each particle of metal leaving the rod is very small. The particle is still further subdivided because it enters a stream of gas travelling at high velocity. The metal particles are not more than 1/100 mm in diameter and are projected at a speed of 300–600 ft/sec over a very small distance, not more than 8 in., between the pistol nozzle and the work face. The time of flight is therefore of the order of 1/750th of a second. The small drops, like weld metal, arrive at the work surface in the molten state. Being so small they solidify quickly, and this explains the differing results between spraying and welding. Before solidification the drops tend to splash out, and as there are so many of them in the stream the splashes interlock as they solidify. The surface of the particle is partially covered with an oxide skin, which for some metals is formed at the wire tip, and in all cases is augmented at the work surface. In 1945 the author was able to show all these actions by high-speed cinephotography, but recently Prof. A. Matting and his colleagues in Hanover have produced a far better film, some of it at frame speeds of 3,000 per sec. The material deposited is not homogeneous as in the welding process, but is an interlocking conglomeration of small particles. By special adaptation of the process conditions, *i.e.*, spraying in closed systems by high-frequency heating in an inert gas, no oxide skin can form, and with temperature and speed high, it is possible to produce a homogeneous mass similar to a true weld structure. Even so, the heat content of each particle as it arrives at the surface is so quickly dispersed that, except in special cases, there is no welding between the deposited gas and the work metal. From this, it follows that the surface for receiving a sprayed deposit must be prepared so that there will be some mechanical interlocking. The surfaces of the work and the deposit are interlocked on a microscopic scale. Furthermore, the particles solidifying and meshing one with another, entrap voids, so that the sprayed metal is not as solid as a casting or the metal produced by welding. Differing from good weld deposits, sprayed metals do not usually add strength to the article sprayed. If the coatings are submitted to an after treatment such as annealing, it must be expected that as they are less homogeneous than a cast metal,



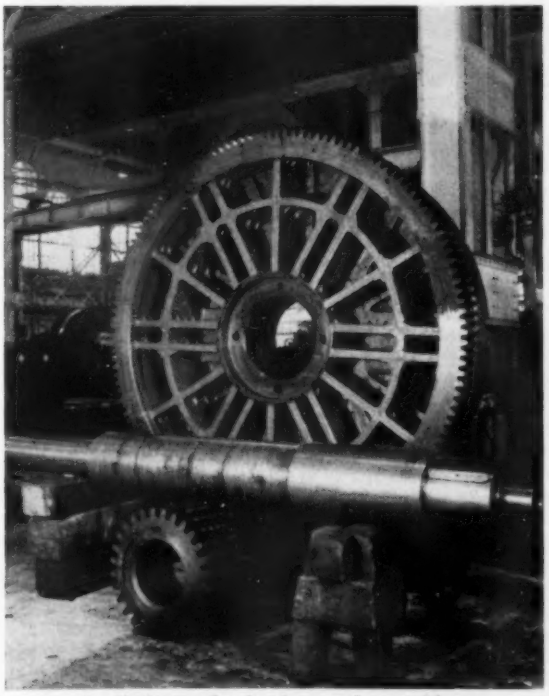
2—*Application of metal spraying to large diameters (propane bottles)*

shrinkage will occur as the voids disappear; a consideration which must be appreciated when solid articles are to be made by spraying. It might appear from the foregoing that the uses of sprayed deposits must be extremely limited and that they should not be used if welding is possible. This is not true; every type of material has a real use and the curious structure inherent in sprayed deposits has not prevented them becoming of great commercial value at the present time, and perhaps they may have an even more important future.

Surface Preparation

The work surface must be prepared in some way to receive the deposit. One of the interesting aspects of the spraying process is that it is virtually cold and that if the pistol is moved fairly rapidly, coatings of very high melting point metals can be applied to delicate fabrics and even to explosives without risk. Naturally, if the pistol is allowed to dwell on one point for a long time the work surface gets hot but never hot enough to cause welding.

The ideal surface for the reception of sprayed deposits is one which is cleaned and roughened to make the hills and valleys of comparable size to the particles themselves. This can be achieved by grit blasting with angular particles of 6–15 mesh per cm. In England we are not allowed, for health reasons, to use silica sand for blasting, although it is a very good abrasive. The grit used is either chilled steel of the angular variety or ground fused alumina. There are some furnace slags, notably from copper refining,



3—*Shaft re-surfaced with a metal-sprayed layer*

4—*Modern type of metallizing pistol*

which are hard enough to be used once in a blasting machine, but they seldom can be recirculated, for they break up too easily. Steel grit and alumina can be recirculated for a number of times. There are two methods of projecting the abrasive, one by allowing it to mix with a stream of compressed air and blowing it on the surface, the second by throwing the grit from wheels revolving at 2500 r.p.m. This latter method is used only for large structures. For crankshafts and engineering articles grit blasting by compressed air is normal, the air pressures used being between 40 and 85 lb/sq.in.

When the use of spraying for reclamation work became common, means were sought to increase the adhesion of the deposit to the base metal, because under severe torsional stress the applied metal could sometimes be twisted off a shaft that had merely been grit blasted.

Three main methods were tried:

(i) For a cylindrical shaft, the work surface was threaded with a 60° pointed tool, using from 6 to 10 threads per cm, with a depth of 0·5–0·75 mm

An alternative was to cut grooves, 6 to the centimetre, and about 0·5 mm deep, by means of multiple cutters, the grooves being cut so that the lands between them could be knurled with a special tool to give a dovetail effect

(ii) When the surface was too hard to be grit blasted or machined, it was roughened by electric bonding, *i.e.*, spattering with a low-power welding set using a bundle of nickel wires as electrodes, these being surrounded with a compressed air jet. The peak height of the spluttered metal was 0·5 mm

(iii) The work surface was well cleaned and abraded with medium-grade emery cloth, sprayed with molybdenum to a radial thickness of 0·05 mm. In this case the work could be slightly preheated before spraying.

Immediately one is faced with the question of how these methods of preparation affect the mechanical properties of the articles. Much more research could be profitably carried out on this matter, but some indications can be stated, largely due to the work of W. Lee Williams of the U.S. Naval Engineering Experimental Station at Annapolis, and to D. Birchon of the Admiralty Materials Laboratory at Poole.

More recently two important papers on the subject

have appeared, one by V. Linhart and E. Kretzschmar reporting on work done in Prague and Halle, and the other by E. Nadasi of Budapest.

Williams,[1] who did not discuss the molybdenum method reported that, if the bond strength is adequate, the grit blast process is the safest, and the electric bond method the least desirable from the standpoint of stress concentration, but preferable to rough cutting or grooving on small parts because of the smaller undercut necessary. Rough threading was less damaging than grooving for parts subject to flexural stresses, though both exerted about the same effect in torsion. The flexural stresses were determined by rotating cantilever tests. In alternating torsion fatigue tests, the effects of rough threading and grooving were similar.

Williams emphasizes the importance of size effect, when using such methods for preparation for metal spraying, and for large shafts above 5 cm diameter there would seem to be little objection to rough threading. This conclusion has been amply born out in practice, for many hundred thousand of shafts have been so treated without subsequent failure due to fatigue.

The work of Williams has been largely confirmed by Nadasi[2] who makes certain other useful points. He prefers the threading tool to have a rounded tip with a negative angle of 5° and clamped a little under centre. He thinks that the final deposit should not be less than 0·8 mm over the crest of the thread, and finds little difference with different thread profiles. In common with most other workers in the field he stresses that the coarseness of the thread can be increased with larger shafts and that the adhesion can be increased if grit blasting follows threading and if great care is taken to blow out all abrasive from the recesses.

The electric bonding process, which is slow, is little used except for the treatment of materials of such hardness that grit blasting and rough turning are unsuitable.

The work of Linhart and Kretzschmar[3] indicates that the blasting process does not cause a reduction in fatigue limit if used on the surface of a shaft and that it is beneficial when used on coarsely threaded work which normally suffers 40% reduction in fatigue limit. This figure is reduced to 25% by subsequent blasting. These workers report a reduction in fatigue limit of more than 60% when using electric roughening, a process which must be used only when other methods are not available. As would be expected, the notch effect decreases with increasing diameter of the component, and parts that have notches necessitated by design do not necessarily suffer further by being roughened. In general these workers have proved that surface preparation properly carried out is unlikely to reduce fatigue strength beyond the reserve normally allowed in design.

Use of molybdenum to improve adhesion

When molybdenum wire became a commercial possibility it was realized that it might, owing to the properties of the metal, give an alternative method of improving adhesion. It was claimed, in a patent held by the Metallizing Engineering Co. Inc., of New York, that this metal could be sprayed directly onto a clean but otherwise unprepared surface, giving good adhesion. As a general rule it was soon found that some form of preparation, for example cleaning with emery cloth or light grit blasting, was important. The combined operation, *i.e.*, some form of preparation and spraying with molybdenum, is now in general use.

The metal molybdenum has a high melting point of 2630°C. and has a high specific heat. The heat content of each particle must be high compared with other metals and yet its oxides melt at a low temperature, about 750°C., and volatilize easily. Each sprayed particle therefore will be clean on reaching the work surface, and in some cases there is evidence that incipient welding takes place. Some workers are inclined to attribute the high adhesion of the metal to this effect only, but it is much more likely that other factors, such as electron exchange in a matching crystal lattice, may play a part. Some discussion on these matters has been published by Sheila Holgate.[4] Molybdenum bonds satisfactorily, although to varying degrees on stainless steels, Monel, nickel, and chrome-nickel alloys, cast iron and steel, and most magnesium and aluminium alloys. It does not bond well to copper, bronze, and brass.

In Great Britain, for crankshafts and other shafts working at high stresses, the only forms of preparation allowed in Government Specifications are grit blasting or molybdenum bonding over a clean emery-clothed surface. The conditions of spraying are laid down in Specification EM 5118.

Birchon[5] made a study of preparation methods and generally confirmed the work of Williams, but in addition he gave special attention to molybdenum. It is impossible in this paper to give more than a brief summary of Birchon's work, but his expanded conclusions are as follows:

(1) The application of a thin layer of molybdenum between steel and the main sprayed metal enhances the adhesion obtained
(2) The combination of a grit blasted surface and a molybdenum underlay produces adhesion comparable with that resulting from direct deposition on a rough threaded finish, *i.e.*, 3000–4000 lb/sq.in.
(3) The application of a moybdenum underlay to a rough threaded finish is not justified
(4) The machined ferritic steels suffer a reduction in fatigue strength (measured by rotating bending) as a result of molybdenum spraying. The effect is broadly proportional to the tensile strength of the basis steel. The steels tested varied from a carbon content of 0·05 to 0·40%, the low carbon alloy containing 8% Ni and 17% Cr. The ultimate stress varied from 32 to 80 tons/sq.in.
(5) Controlled blasting of the surface before spraying can ensure substantial retention of the original fatigue properties even when molybdenum is used
(6) This combination will provide equal adhesion and superior fatigue properties to that resulting from a rough-threaded surface finish, such as may be required to ensure adhesion in the absence of molybdenum.

But it must be stressed that, in common with other published results, Birchon's experiments show a good deal of scatter, and many hundreds of experiments with different steels and methods of preparation would

be necessary to settle definitely all outstanding problems. In passing, it can be mentioned that each particle of sprayed molybdenum is very hard (DPN of 1000 kg/sq.mm) as compared with the hardness of the constituents of steel, namely ferrite 95, pearlite 230 and quasi-martensite 550.

Very often the steels sprayed on to the prepared surface to reclaim a steel article are either a 0·7–0·8% carbon steel or a 13% chromium steel. Occasionally 18/8 and other austenitic steels are used but they should be of the stabilized variety, containing titanium, niobium, etc. Sprayed stainless steel is not stainless unless it is ground and polished.

Finishing Methods

There is a good deal of residual stress locked up in a sprayed deposit, due largely to the chilling effect, and hence the applied metal tends to shrink onto cylindrical forms such as shafts, and increases the practical adhesion to a figure greater than that shown in the plug tests. This is very advantageous when the surface of the article is unbroken, but if it contains key-ways and oil grooves it adds to the practical difficulties. Where possible it is always advisable to chamfer off the edges of these depressions, both to avoid edges in spraying and because it helps to avoid reduction in fatigue limit. For large shafts, the edges of keyways can often be built up with weld metal, using a smaller diameter electrode. The welded fillet, which is stronger than the sprayed deposit, is ground down when the final machining is carried out. Where such methods are not possible, oil holes, etc. are plugged after preparation with moulded rubber, or better still, carbon insets. The spray is made continuous over the inset, which for rubber is very carefully removed after deposition, and for carbon is ground down with the deposit. The spraying process must be continuous and where practicable the total thickness should be applied in one pass. If this is not possible, a large number of very rapid light passes are permissible, but separate layers of medium thickness, 0·1–0·2 mm, are not good practice. The pistol should be set to give as fine a coating as possible, except for molybdenum, which when used as a bond, should be applied coarsely. The flame should not be oxidizing, and the spraying angle should be as near as possible normal to the surface. If the pistol is operating correctly the loss of carbon in steel is very small, but excess oxygen in the flame can cause serious changes in composition and cracking in low-carbon deposits. If a heavy deposit is being applied in one pass from a large pistol it is often advisable to cool the work with compressed air or even with clean water. It must be remembered that the deposits do not add strength to the work, and nothing must be reclaimed after preparation that is not in itself fit for further duty. After grinding or turning to final size, the deposit should not have a radial thickness of less than 0·5 mm. Grinding is the preferable finishing process, and as all sprayed metals tend to load the wheel, they need more frequent dressing; and if fine grain ones are used, clogging may cause chatter. Medium soft wheels, with a No.46 grit, are recommended as are also soft ones with a No.60 grit. The surface speed should be high and the cut light. If turning is decided upon as the finishing process a tipped tool is used. It must be kept well sharpened, cuts should be light and surface speeds should be fairly high.

Applications

Having now described the difficulties of the reclamation method its manifold advantages can be assessed. The first and primary one is that of economics. A medium-sized forged crankshaft, for instance, is an expensive unit and may be rendered unfit for service because the surface of one journal has become worn. Such surfaces cannot be repaired by welding, but a repair can easily be made by spraying. An expensive roll may be rendered unusable by a worn neck, but if the roll is from a finishing mill or some process where the neck is not subjected to heavy impact, metal spraying will save the cost of a new roll. One could enumerate long lists of such everyday problems, including pump rods, press plungers and the like. The process often gives a means of putting back to service machine parts at an expenditure of from 2% to 15% of the cost of a new part.

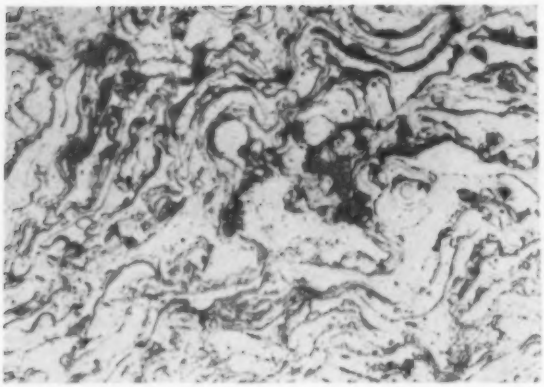
Whilst various steels have been mentioned as suitable for spraying, it must be remembered that copper and nickel and their alloys can be used as deposits; and the process is then very useful for covering hydraulic rams and pump rods. It is good practice to chamfer the ends of the rams or rods and to take the deposit over the end surfaces. This prevents the possibility of the pressurized fluids exerting a lifting action on the coating.

The sprayed deposit is unique in that it has a porous surface and also inclusions of oxide of unusual hardness, giving hard spots in a soft matrix. Such types of material have long been known to be ideal for bearing surfaces. They absorb oil when there is an excess of lubricant and give it up when there is a tendency to dryness. They also tend to give the necessary high spots on which the rubbing surface rides. Many years ago, an independent consultant, Mr. H. Shaw, carried out tests on shafts of petrol and diesel engines, which showed that if the oil was cut off from a new hardened crank shaft, seizure took place in about two hours, and was complete. On a sprayed shaft, a slow seizure occurred in 22 hours, and when oil was restored the shaft worked perfectly. Since that time hundreds of thousands of shafts have been reclaimed, and the number of failures have been very small—these usually due to errors in application or technique.

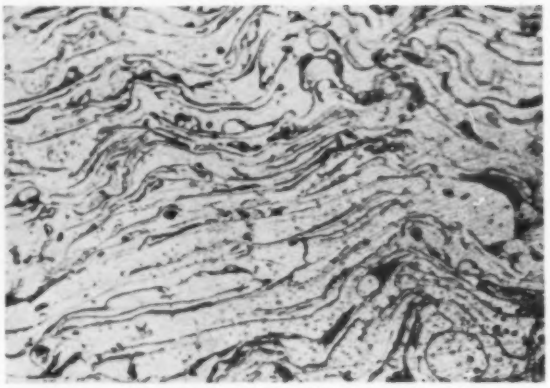
A further word of warning is necessary: that reclaimed shafts do not as a rule behave well with lead bronze or light alloy bearings, unless it is possible to allow a larger clearance than usual. The hard spots of the deposit seem to bind to the lead or low-melting-point metal unless the oil film is thicker than usual.

Another advantage of the process is that it is virtually cold, so that the bearing surface of armature shafts can be reclaimed without the expensive need to remove the windings.

Until the advent of the molybdenum technique it was very difficult to build up flat surfaces, such as lathe beds and slide rests. This is now a common and successful everyday job. As the sprayed deposits contract on the work surface, it follows that some



5—Structure of sprayed 4% C-steel layer made under strongly oxydizing conditions



6—Structure of sprayed 4% C-steel layer made under correct (reducing flame) conditions

difficulties may occur in the treatment of internal surfaces or even those which are concave. Using the wire process and special nozzles, bores larger than 1 in. internal diameter can be treated for a distance of a yard with some metals, such as aluminium and copper alloys, but it is difficult to prepare them by grit blasting.

As the coatings exhibit such excellent anti-friction properties on shafts, one would expect them to be used for repairing and making bearings, whether they be of the complete or half shell type. In Great Britain, such work has not reached any importance, possibly because split shells are comparatively cheap and many large bearings have a very thick layer of white metal, which is better applied by casting. In this latter case, however, where the shells are of cast iron, sprayed tin is used to ensure the best adhesion of the molten white metal to the bearing shell. In the type of bearing composed of a thin layer of bearing metal on, say, a bronze or brass shell, unless adhesion is very good, there is likely to be a steep temperature gradient of the interface of the deposit and the shell, and some local overheating may occur.

In Poland it has been found economically desirable to manufacture bearings by spraying, and at the Second International Metal Spraying Conference held in Birmingham under the auspices of the Association of Metal Sprayers, in October 1959, Dr. Ing. Stanislew Gabalski, described some of the work done, and Tadeusz Drazkiewicz of the Institut Mechanik Precyzyjnej, Warsaw, described his work on the compressive strength of spraying deposits. He showed that the first effect of pressure was to close the pores of the metal, causing a contraction in size followed by work hardening. For instance, with bronze a pressure of 32 tons/sq.in. caused a 9% upsetting in form, but the safe pressure would be 19 tons/sq.in. It is therefore evident that bearings should be able to sustain very heavy pressures in practice. Gabalski suggests that at a maximum rubbing speed of 16 ft/sec the pressure should be at a maximum of 2500lb/sq.in., when the bearing is made by spraying a lead-cored copper wire giving a 50% mixture of copper and lead.

It is suggested that by spraying powders of aluminium and lead together, cheap bearings could be made. Practically, an experience is given of the use of sprayed bearings for the cranks of a 10-ton lorry engine of 120 h.p. After 62,000 miles running, the diametrical wear on the bearings was 0·075 mm and on the shaft 0·025 mm.

Undoubtedly there is much that could be done with the process as a means of improving bearings. As with shafts, the major advantages would seem to be with large machines, where the cost of replacement is high.

Hard-facing by spray welding

There has long been a need for the application of wear-resisting surfaces to pump rods, shafts, etc., and to some extent this has been met by welding on to the article a layer of "Stellite" or some other hard alloy. The process, though effective, is slow and costly, as the material applied will need to be finished by grinding, and if there is need to remove more than a small amount, it represents a difficult technique. With the growth of the oil industry in particular, there was room for a method of applying such materials which could be completed with some precision, so that final machining could be cut to a minimum and the time of application reduced.

The possibility of using a spray method was reached with the introduction of certain alloys, which were

7—A shaft being sprayed with Colmonoy powder

known generally as the "Colmonoy" alloys. The range most generally used for spray welding is 65–75% Ni, 13–20% Cr, 2·75–4·75% B, and with iron, silicon, and carbon together not more than 10%. The alloy layer has a hardness of 56–61 (Rockwell C) and it fuses at a temperature of 1020°C. The main property which makes this material so suitable for the process is the very wide plastic range around its fusion temperature. The powder, which has a specific gravity of 7·8, is sprayed from a powder pistol on to the article, which has already been prepared by grit blasting. If the coating applied is to a thickness of 1 mm, the theoretical coverage is about 140 sq.in. per pound. Taking a shaft, as an example, the component is undercut to allow for the thickness of the coating and is rotated at 30–50 ft/min surface speed, and the deposit is applied by multiple passes each about 0·2 mm thick. An allowance of 20% must be made for shrinkage during fusing, and a finishing allowance of at least 0·25 mm.

For example, for a part undercut 0·9 mm in radius the coating thickness would be:

Undercut on radius	0·900 mm
Allowance for finish	0·025 mm
	0·925
20% allowance for shrinkage	0·185
Total before fusing	1·110

For internal bores the part can be preheated to 200°C. Immediately after spraying the coating must be fused with (*a*) an oxy-acetylene torch; (*b*) a controlled atmosphere furnace; or (*c*) by induction. The torch method is the most general. The flame is played on the base metal near the deposit until the surface is a dull red heat. The flame is then allowed to move slowly over the deposit until this glazes or shows a mirror-like gloss. Large parts may be preheated to 300°C. before fusing. The part is now removed and cooled very slowly in lime or keiselguhr. The deposits can be machined with carbide tipped tools, using a fine feed, say 0·8 mm per revolution and approx. 16 ft/min spindle speed. If the deposits are ground a silicon carbide wheel is used with light fast cuts. The surface resists most corrosive influences very well and a hardness of 650 D.P.N. has been reached with a low coefficient of friction.

The success of the Ni-based Colmonoy alloys has caused the exploration of the similar series of cobalt alloys under the generic term "Stellite". The process and results are similar. Deloro Stellite Company have made a considerable advance in the technique by using a light sensitive cell to follow the fusion process and automatically advance the torch so that the human element is eliminated.

There are some requirements for even harder deposits, and these can be met by mixing the Colmonoy or Stellite powder with tungsten carbide. This remains as a very hard network in a matrix of the nickel or cobalt alloy. While the Colmonoy alloys are used in the form of powder, some of the Stellites are made in rod form and can be sprayed from a wire pistol, which reduces the loss in application.

The hard-facing processes are becoming very important, not only in the oil industry, but for the treatment of pump rods in the chemical industry, the surfaces formed being resistant to many forms of chemical attack. They give a method of applying hardness on the surface of rough materials so that the component resists both shock and abrasion, conditions often met in arresting gear for fast aircraft.

Ceramic Spraying

Since the early days of the spraying process, a good deal of attention has been given to the possibility of spraying ceramics and the glasses. No difficulty was found in making deposits with glass, especially when the material was of a low melting point. Glass could be sprayed as powder or from rods, but all attempts to spray mechanical mixtures of the ingredients of the glass, in the hope that spraying would bring about vitrification, failed. It seemed that pre-sintering into the super-cooled conditions was necessary before spraying. It soon became apparent that such deposits of glass, in common with all other sprayed layers, contained locked-up stresses of considerable magnitude. Attractive coatings deposited on metals crazed in storage, especially if there was a wide temperature range. Such stresses could be removed by annealing at high temperatures, followed by slow cooling, but the need for such after-treatment completely nullified the advantages of spraying, and as far as glasses were concerned the normal process of virtreous enamelling held the field.

In the past few years the Norton Company of America, after long research, developed a process for depositing materials such as alumina, zirconia, and zircon (zirconium silicate). The first results using powder were not good, but it is possible that powders of the correct crystalline structure were not used. For reasons not yet fully understood, it appears that in all processes demanding rapid fusion and sudden chilling it is necessary to start with a material with an ordered structure. The experience led the Norton Company to manufacture rods 3 mm in diameter and more of certain ceramics of the correct crystalline form, the process being known under the trade name "Rokide". These rods are sprayed from wire pistols, which are suitably geared to give advances of a few centimetres per minute. Sometimes, this is achieved with electric motors with reduction gears and a flexible drive, but the most modern hand pistols with air motors and magnetic governors can be used for the purpose. The work material is grit blasted in the ordinary way, and the deposit of alumina is in the more unusual gamma form. Descriptions of the structure have been given by Plummer and Rooksby.[6] The deposits are porous to about 10% and do not protect mild steel against high temperatures for long periods. Since coatings are extremely good heat insulators they should be deposited on heat-resisting steel, but it is sometimes possible to overcome the difficulty by using mild steel sprayed with Nichrome on which the alumina is applied.

Recently, W. Stanton of Metallisation Ltd. has patented a process which seems to have promise, using sandwiches of alumina and a metal having a high-temperature plastic range. The alumina coating is very hard (Knoop 2000), but can be ground with a diamond

wheel. The surface is still porous and therefore offers good bearing properties, and is used for making bearings for lubricants other than oil, such as water and liquid oxygen. The coatings are used for rocket throats, pyrometer sheaths, and so on.

Since the advantages of the "Rokide" process are obvious, there have been developments in the spraying of powdered alumina and other refractories. These represent a cheaper process, for the material need not by pre-sintered, provided that the crystalline form is right. The powder process does not, however, give a so firmly adherent or non-porous coating. There is no doubt that there is a considerable future for the spraying of ceramics, especially when it is possible to use materials such as titanium boride which are not wetted by molten metals.

An interesting use for the "Rokide" process is for the mounting of strain gauges used at elevated temperatures. The gauge wires are embedded in the oxide coating.

It is obvious that in a paper of ordinary length it is impossible to deal with all aspects of spraying as adapted to engineering parts, but it is hoped that the successes achieved so far will dispel the early ideas of the dangers of its adoption. The potential savings cannot be ignored by makers of machine tools and plant engineers, and the possibilities of the surface finishes available deserve the attention of all really progressive designers. But it must be stressed that, in common with all technical processes, it requires reasonable care in application—expert advice is usually available.

REFERENCES

1. W. L. WILLIAMS: *Bull. Amer. Soc. Test. Mat.*, 1949, vol. 49, pp. 683–701.
2. E. NADASI: *Schweisstechn* (Berlin), 1959, vol. 9, pp. 89–92.
3. V. LINHART and E. KRETZSCHMAR: *ibid.*, pp. 83–89.
4. S. M. HOLGATE: *Electroplating Metal Finishing*, 1955, vol. 8, pp. 219, 226.
5. D. BIRCHON: *Metallurgia*, 1958, vol. 58, Dec., p. 273.
6. M. PLUMMER and H. P. ROOKSBY: *J. Appl. Chem.*, 1958, vol. 8, pp. 35, 44.

INTERNATIONAL INSTITUTE OF WELDING

Use of Reference Blocks for Checking Ultrasonic Inspection Apparatus

Commision V – Testing, Measurement and Control of Welds

Purpose of the Experiments

IN THE course of its work, Commission V has considered, and even recommended, the use of reference blocks to determine the possibilities and to check the settings of equipment used in the ultrasonic inspection of welds. Two proposals for reference blocks were received, one from the Dutch delegation (Fig. 1), the other from the British delegation (Fig. 2). The Commission decided to ask its Sub-Commission C *Ultrasonics* to make a comparative study of the possibilities offered by the use of each of these blocks.

A first series of tests was undertaken during 1955–1956, and the results seemed to favour the block proposed by the Netherlands delegation, which appeared to offer possibilities of wider application than the British block.

However, the British delegation was able to convince the Sub-Commission, at its meeting held in Paris on 2nd March 1956, that the British block offered the same possibilities as that proposed by the Netherlands delegation. Only the lack of precise information on the use of the British reference block has prevented the various investigators from verifying all its possibilities.

The first results of the tests having thus been called in question, it was decided to resume the investigations on a new basis and to carry out comparative tests in Belgium, Denmark and France, so as to reach conclusions on "the possibilities of use of the blocks".

These arrangements having been adopted in the course of discussions at the Annual Assembly in Madrid in 1956, the three countries mentioned above, together with Switzerland, resumed work on the basis of documents prepared by the sponsors of each of the two blocks.

Nature of the Tests

The purpose of the reference blocks was defined as:

(i) To control the apparatus and the probes so as to determine their characteristics
(ii) To adjust the sensitivity for inspection and to control it so that it remains constant during the whole of the inspection

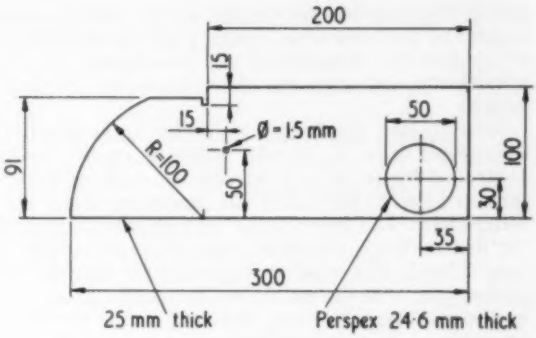
---

Report IIW/IIS-23-59 (ex. doc. V-56-57) of the International Institute of Welding.

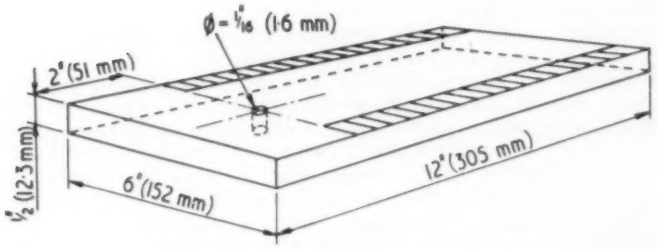
(iii) To reproduce the adjustments previously used
(iv) To compare, where necessary, the possibilities of different materials for a given operation.

The experiments dealt principally with the comparison of the possibilities of the two reference blocks, in regard to points (i) and (ii), these reference blocks enabling, in principle, the following operations to be carried out:

Adjustment and checking of the apparatus
(*a*) Calibration of the scale
(*b*) Adjustment of the relative sensitivity
(*c*) Control of the dead zone
(*d*) Control of the power of resolution
(*e*) Control of the linearity of the time base.



1—*Dutch reference block*



2—*British reference block*

Control of the probes
(*a*) Determination or checking of the beam index
(*b*) Determination or checking of the angle of incidence
(*c*) Correction of the zero point
(*d*) Determination of the beam characteristics.

Conclusions Drawn from the Experiments

Conclusions of each expert

The four experts appointed carried out experiments on the blocks, following the directions for use appearing in Appendices 1 and 2. They reached the following conclusions, in connection with the points defined in the preceding paragraph:

Belgium. Although the two blocks are very useful and in several cases there is nothing to choose between them, in general there are advantages in using the Dutch reference block, account being taken of its special qualities for certain control operations, and this in spite of its greater weight and its more costly manufacture.

Denmark. It is obviously impossible to produce a simple reference block with which one can achieve all kinds of control or settings necessary for all probes and all types of apparatus within every range. It must, therefore, be decided whether to use a single standard block, enabling as many control operations as possible to be carried out, or several types of specialized blocks. For example, it may be said that, for the application of the transmission method, neither the Dutch nor English block is really suited to the control of the equipment.

Nevertheless the possibilities offered by the British and Dutch blocks were studied. In the opinion of the Danish expert, there is no doubt that the Dutch block is to be preferred, since it offers many more possibilities for the control of equipment and is simpler and more accurate than the British one.

The Dutch block has the considerable advantage of providing almost all the results by direct reading, whereas, for the British block, calculations and the use of a slide-rule or trigonometrical tables are necessary.

Owing to its dimensions, the British block seems preferable for the control of equipment using the double-probe system with separated transmitter and receiver on plates thinner than 0·5 in. (12·7 mm) 70° angle. By comparison with the method using transceiver probes, this system is not, however, sufficiently effective for the practical inspection of welds outside the laboratory, so that this advantage of the British block is of little importance.

France. For apparatus equipped with transceiver probes, the two blocks can render much the same services, but the Dutch block has advantages that are not negligible.

This block makes it possible to carry out control tests more quickly and more accurately without the need for previous calibration, whilst calculations and the use of trigonometrical tables are unnecessary.

It is therefore possible, with this block, to follow continuously, by means of successive checks, the working of the equipment, in so far as many of its characteristics are concerned (amplification, energy, linearity, resolution, etc.)

In addition, the Dutch block has a more 'universal' character, since it enables apparatus equipped with longitudinal wave probes to be controlled.

On the other hand, the English block is very suitable for the control of equipment with separate probes, for which the Dutch block does not appear to be well adapted. However, the British block could cope better with the problems raised in the inspection of welds if some small modifications were made to it, both in regard to design (addition of a ruler with reference

scales—use of a direction device for the probes in the control of the transmitted energy), and in the method of calibration (elimination of uncertainties in the adjustment and rigorous calibration by graphical means).

Nevertheless, the Dutch block has some practical advantages over the British block in regard to the control of the point of incidence, the angle of refraction, and the calibration of the measuring scale.

Switzerland. The experiments have shown that, using the British block, the adjustment of the equipment is very difficult. The wave trains hitting the hole as well as the sides of the block do not produce a clear echo on the oscilloscope screen, and the point at which the echo reaches its maximum height is not well defined.

On the other hand, the Dutch reference block offers too many possibilities, as it lends itself to the control of longitudinal and shear wave probes. In the present state of investigations, it seems that, without producing a new block, it would still be possible to simplify the Dutch block; for example, in the same way as has been done for the block at present used in Switzerland.

General conclusions

From the results as a whole, it is clear that there is a certain preference for a type of reference block based on the Dutch proposal.

This preference is mainly to be attributed to the two following facts, which were often mentioned by the various investigators in connection with the Dutch block:

(*a*) The measurements are effected in a direct way, without any need for calculations, which are always tiresome, even if they are simple;
(*b*) The measurements are generally more accurate, the maxima of echoes being sharper, thus making it unnecessary to use advance calibration operations for each probe.

Moreover, a reference block of the type proposed by the Dutch delegation has a much more universal character, which is an advantage. Indeed (and this was underlined by several investigators) it may be necessary in the inspection of certain types of weld to use longitudinal wave probes. The calibration of these probes must therefore be taken into consideration and, in that case, only the Dutch block makes this possible.

These observations do not detract in any way from the proved qualities of the British reference block, and one of the French investigators thought that it would be advantageous to be able to combine in a single reference block of suitable shape the respective advantages of the Dutch and British blocks.

In the light of the reports prepared on this subject, Commission V, at the Essen meeting in 1957, adopted a resolution which was approved by the Governing Council and which recommended the use of a reference block based on the foregoing conclusions, account being taken of any modifications or improvements proposed, and, in particular, of a wish expressed by the United Kingdom delegation to make provision for a sufficient area for the use of equipment with two probes.

The United Kingdom delegation commented on these reports (*see* Appendix 3).

The modifications or improvements proposed were examined by the group of experts which carried out the tests on the two blocks. Finally, on the proposal of its Sub-Commission C *Ultrasonics*, Commission V decided at the Vienna Annual Assembly in 1958 to adhere to the terms of the resolution adopted in Essen and to leave users free to choose from the various possibilities considered (*see* Appendix 4).

In conclusion, the reference block recommended by Commission V for the control of ultrasonic testing equipment should be in conformity with the indications given in Appendix 4, it being understood that, in matters of detail, the choice between the various possibilities proposed is left to the judgement of the user.

Appendix 1

Directions for Use of the Dutch Reference Block

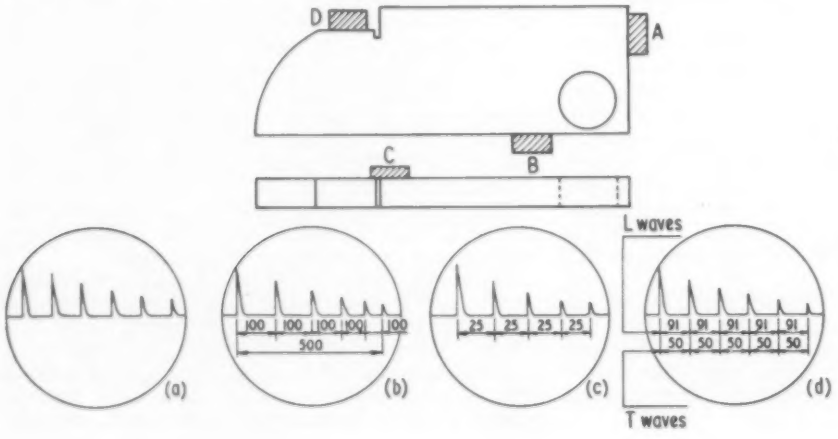
SETTING AND CONTROL OF EQUIPMENT

Calibration of range and control of linearity of time base

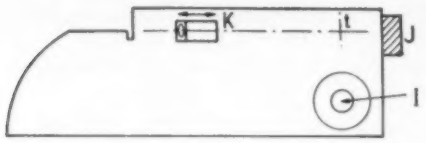
Since this calibration has to be carried out both for longitudinal and transverse waves, both cases have to be considered.

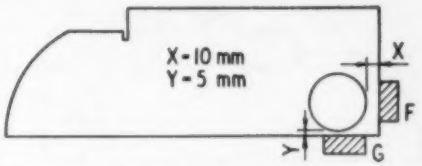
Longitudinal waves

(*a*) Ranges below 200 mm (8 in.)—
Position of the probe: *C* (Fig. 3)
Appearance on the screen: Fig. 3*c*

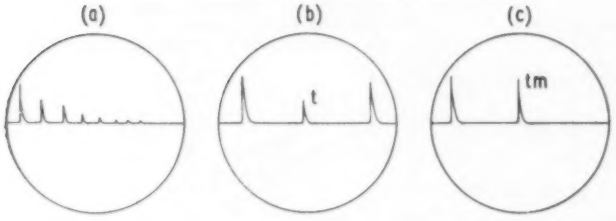


3—*Calibration of time base:* (a) *Linear scales of 1 m (position* A*) and of 500 mm (position* B*);* (b) *non-linear scale of 500 mm (position* B*);* (c) *linear scale of 100 mm (position* C*);* (d) *linear scale of 250 mm (position* D*)*

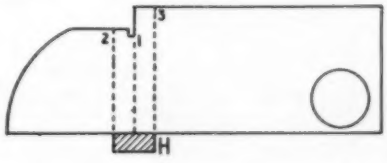




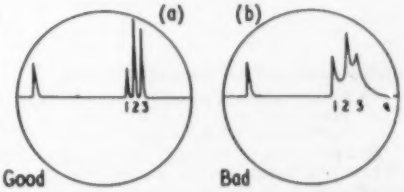
5—*Check of dead zone*



4—*Setting of relative sensitivity*



6—*Check of resolving power*



(*b*) Ranges above 200 mm (8 in.)—
Positions of probes: *A* and *B* (Fig. 3)
Appearance on the screen: linear scale Fig. 3*a*;
non-linear scale Fig. 3*b*.

For these determinations, the distance to be taken into consideration is that corresponding to successive bottom echoes, for the distance between the emission signal and the first bottom echo is always slightly different from the real value because of the ringing of the probe.

Transverse waves:

Calibration in transverse waves can be carried out from longitudinal waves using the distance of 91 mm of steel which corresponds to 50 mm in transverse waves (this correspondence was found satisfactory during the tests carried out).

Position of the probe: *D* (Fig. 3)
Appearance on the screen: Fig. 3*d* in the case of a linear scale.

Setting of the relative sensitivity

For each job, the setting of the sensitivity is generally carried out at preliminary tests when, for example, a standard test piece containing a weld with defects, the nature of which can be determined by radiographic inspection, is used. With this test piece the setting is sought which enables the greatest flaw detection sensitivity to be obtained.

Two possibilities exist: because of its shape the test piece may or may not give rise to a bottom echo.

If it does, the amplitude of the bottom echo should be noted so that it may be possible later to find the appropriate setting, which will bring the bottom echo to the same amplitude.

If it does not, the reference block is used as indicated in the following, the sensitivity level being marked off so that the corresponding settings may subsequently be found.

Longitudinal waves

(a) High powers—
Position of the probe: *I* (Fig. 4)
Appearance on the screen: Fig. 4*a*.

The thickness of the piece of Perspex is calculated to correspond to 50 mm of steel.

To mark off the setting, the number of echoes and the height of the last of them are noted.

(Note: It is possible in the same way to control the maximum power and amplification of the apparatus.)

(*b*) Low and medium power—
Position of the probe: *J* (Fig. 4)
Appearance on the screen: Fig. 4*b*.

By moving the probe, the maximum amplitude of the echo from the 1·5 mm diameter hole is sought, no account being taken of the bottom echo. The maximum amplitude of the echo from the hole constitutes in these conditions a relative measure of sensitivity.

Transverse waves

Position of the probe or probes: *K* (Fig. 4) (with one or two probes)
Appearance on the screen: Fig. 4*c*.

The probe (or both probes) is moved so as to obtain the maximum amplitude for the hole, and the corresponding position on the block is carefully noted as well as the amplitude of the echo and its position on the dial (this last measurement can be made only if the calibration of the scale and the correction of the zero point have been correctly carried out).

Check of the dead zone

There is no question here of a precise measurement, but only of an approximate check of the dead zone. In any case, this test can be carried out only with longitudinal waves.

Positions of the probe: *F* and *G* (Fig. 5)

(Note: Positions *F* and *G* can also be used for the calibration of small scales, *e.g.*, below 50 mm.)

Check of resolving power

This check is carried out only with longitudinal waves.

Position of the probe: *H* (Fig. 6)
Appearance on the screen: good resolution Fig. 6*a*; bad resolution Fig. 6*b*.

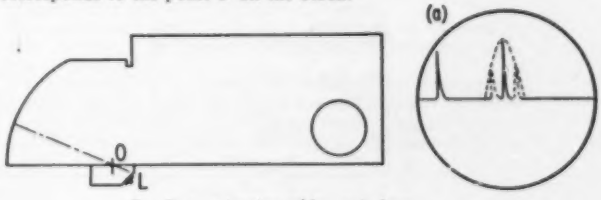
DETERMINATION OF PROBE CHARACTERISTICS

Determination of the beam index

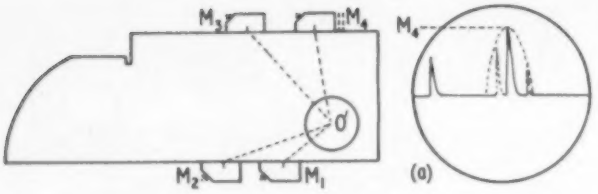
This determination is carried out only with transverse wave probes.

Position of the probe: *L* (Fig. 7)
Appearance on the screen: Fig. 7*a*.

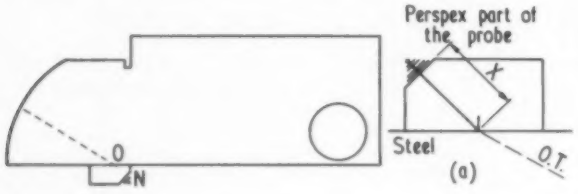
The probe is then moved so as to find the maximum signal amplitude. When this maximum is reached, the beam index corresponds to the point *O* on the block.

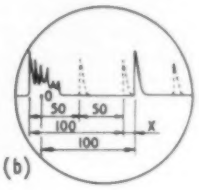


7—*Determination of beam index*



8—*Determination of refraction angle*





9—*Correction of zero point.* (x = *displacement in Perspex part of probe*)

Determination of the angle of refraction

This determination is carried out only with transverse waves.

Position of the probes: M_1—M_2 . . . . . M_n (Fig. 8)

Appearance on the screen: Fig. 8*a*.

By moving the probe the maximum signal amplitude is sought. When this maximum is reached the angle of refraction is determined from the beam index previously defined.

Correction of the zero point

The presence of the Perspex in the transverse wave probes causes a considerable time lag between the moment at which the signal is emitted and that at which it effectively penetrates into the specimen (Fig. 9*a*). Account must be taken of this delay in the calibration of the scale, zero on this scale corresponding on the screen to the moment when the signal penetrates the material to be examined. It is therefore necessary to make a correction of the zero point.

The scale having been previously calibrated as indicated, on the distance of 91 mm, the procedure is as follows:

Position of the probe: *N* (Fig. 9)

Appearance on the screen: Fig. 9*b*.

The zero point may be deduced from the previous calibration as indicated in Fig. 9*b*. It is also possible to adjust the echo corresponding to the path of 100 mm so as to make it coincide exactly with the position on the screen corresponding to 100 mm, this position being defined by the previous calibration in longitudinal waves.

(Note: The modifications proposed for the block tend to simplify the correction of the zero point by making unnecessary a previous calibration in longitudinal waves.)

Determination of the beam characteristics

With transverse wave probes it may be interesting to determine the beam characteristics by tracing conventional polar diagrams, horizontal or vertical, for the beam.

Vertical polar diagram

Position of the probes: M_1—M_2 . . . . . M_n (Fig. 8)

The probe is moved on both sides of the position corresponding to the maximum amplitude, and the amplitude of the echo for each position is noted in relation to a given angle.

It is then possible on a polar diagram to transfer for each angle the length proportional to the amplitude of the successive echoes, which makes it possible to determine the angle of divergence of the beam.

Horizontal polar diagram

Position of the probe: *K* (Fig. 4)

The probe is rotated from one side to the other at the position corresponding to the maximum echo amplitude for the 1·5 mm diameter hole. The corresponding echo amplitudes and angles are noted and the polar diagram is plotted as previously described.

Appendix 2

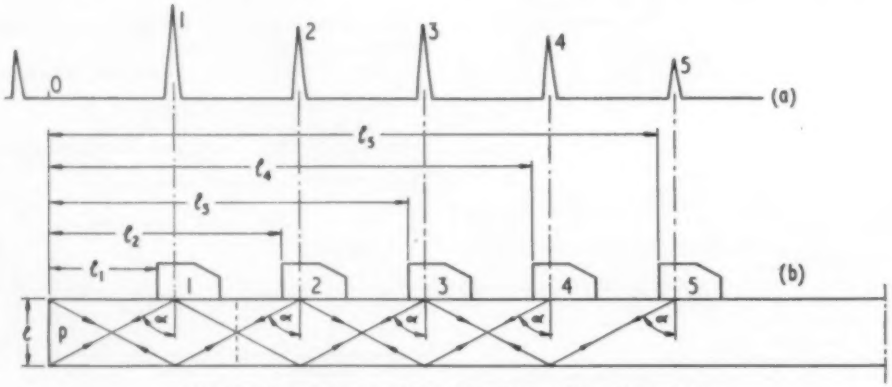
Directions for Use of the British Reference Block

The British reference block is mainly intended for the checking and control of equipment in which only transverse wave probes are used.

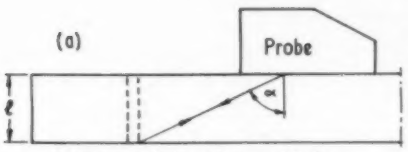
SETTING AND CONTROL OF EQUIPMENT

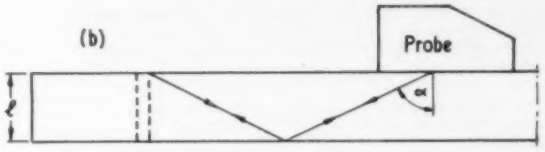
Calibration of scale and control over linearity of time base

The probe is placed on the block, as indicated in Fig. 10. The position is sought in which the maximum signal amplitude is obtained by reflection in the lower corner of the block (position 1). The distance between the front of the probe and the edge of the block is noted (that is to say l_1) and also the position of the corresponding echo on the screen (echo 1, Fig. 10*a*).

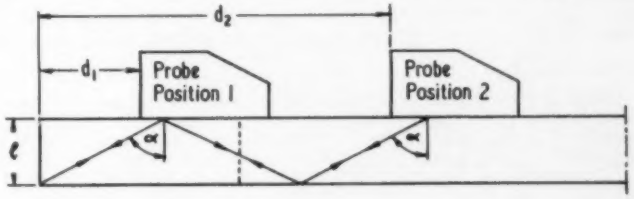


10—*Time base calibration;* (a) *Pulse positions;* (b) *probe positions*

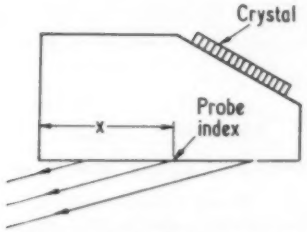




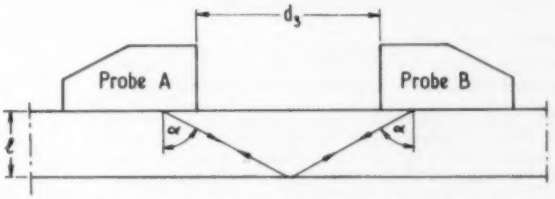
11—*Scan on* (a) *Base of hole;* (b) *top of hole*



12—*Probe index determination*



13—*Enlarged view of probe index in relation to radiation characteristic*



14—*Determination of probe angle for double-probe system with probe indices known*

The probe is then moved to positions 1—2—3 . . . . . n (Fig. 10*b*) successively, the maximum signal amplitude being sought in each case.

The distance measured on the screen between each signal is proportional to the path of the ultrasonic waves in the steel, and this enables the linearity of the time base to be controlled.

Furthermore by calculating the value of the path by one of the following equations:

$p=(l_2-l_1)\operatorname{cosec}\alpha=(l_3-l_2)\operatorname{cosec}\alpha=\ldots\ldots=\{l_n-(l_n-1)\}\operatorname{cosec}\alpha$

it is possible to calibrate as a length the time base of the ultrasonic path in the steel.

Scales giving directly the value of p as a function of the probe index of each probe can be placed along the reference block.

Setting of the relative sensitivity

This setting is carried out in relation to the hole of $\frac{1}{16}$ in. dia. (1·5 mm).

The probe is placed on the surface of the block at a distance from the hole corresponding to a scanning position giving the maximum signal amplitude. This position may correspond to a reflection of the beam on either the top or bottom of the hole (Fig. 11).

The height of the echo is then set by choosing on the screen a certain number of divisions of the vertical scale.

Periodic checks on the flaw detection sensibility may be made during measurement, by returning the probes to their standardizing positions, as determined at the time of calibration.

DETERMINATION OF PROBE CHARACTERISTICS

Determination or control of the probe index

For this determination, the probe is first placed in position 1 (Fig. 12). The position of deep reflection from an edge of the block is then sought. For this position, the value of d_1 is noted, this corresponding to the distance between the front of the probe and the edge of the block.

The probe is then moved back to position 2, so as to obtain the maximum signal amplitude on the same angle of the block as previously, but after two reflections of the beam. The new distance from the front of the probe to the edge of the block is then noted (d_2).

Calling x the distance between the front of the probe and the probe index (Fig. 13), then:

$$x=\frac{d_2-3d_1}{2}$$

This method is also applicable to a double-probe system, with identical probes. In this case, both probes are held side by side and moved as a single unit.

Determination or checking of the probe angle

Several cases must be considered:

Single probe with index known

The probe is placed in positions 1 (Fig. 12), as previously indicated, and the distance d_1 corresponding to the maximum signal amplitude is determined.

The probe angle is calculated from the formula:

$$\tan\alpha=\frac{d_1+x}{t}$$

where t represents the thickness of the block.

Single probe with index unknown

The probe is placed successively in positions 1 and 2 (Fig. 12) and d_1 and d_2 are determined as already indicated.

The probe angle is calculated from the formula:

$$\tan\alpha=\frac{d_2-d_1}{2t}$$

Double probes with indices known

The probes are placed facing each other, as shown in Fig. 14, and one of them is then moved to find out the position of maximum signal amplitude with a single reflection of the beam.

If, in these circumstances, d_3 represents the distance between the probe fronts, the angle can be determinedd by the formula:

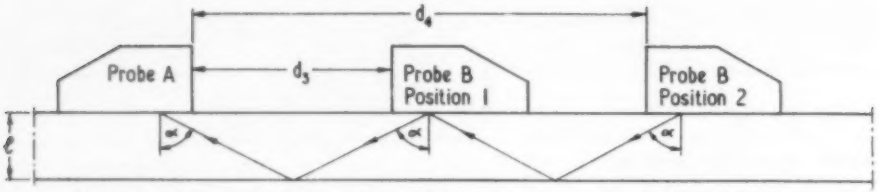
$$\tan\alpha=\frac{d_3+2x}{2t}$$

Double probes with indices unknown

The probes are placed facing each other and the distance d_3 is first determined in the way indicated in the preceding paragraph.

One of the probes is then moved until a second position of a maximum signal is found, but after three reflections of the beam (Fig. 15). In these conditions, d_4 represents the distance between the probe fronts. The probe angle can then be drawn from the formula:

$$\tan\alpha=\frac{d_4-d_3}{2t}$$



15—*Determination of probe angle for double-probe system with probe indices unknown*

(Note: It may be remarked that, in all these matters of probe angle determination, it is not usually necessary to determine the angle itself. In fact, in the majority of applications relating to the inspection of welds, it is the tangent which is usually of value.

Consequently, if, with one probe, the value of the angle is given or if this value is measured directly, it is necessary to consult a table of tangents to obtain the tangent of the angle. It therefore appears useful to determine this tangent directly.)

Correction of the zero point

The zero point can be corrected from the calibration of the time base, which is carried out as previously indicated (*see* Fig. 10).

If the time base is sufficiently linear, the zero point on the scale can be found by measuring to the left of pulse 1 (Fig. 10*a*) a distance equal to that between pulses 1 and 2. This may then be taken as the true zero point and all path distances measured from it.

Determination of the beam characteristics

The flaw detection sensitivity being set to a given value, the beam characteristics are determined as follows:

(i) The probe is placed on the block with its front edge near to the top of the hole of $\frac{1}{16}$ in. dia. (1·5 mm). The probe is then moved backwards in steps of the desired magnitude, the hole always being kept in the central plane of the probe. For each position of maximum of the probe, the amplitude of the echo and its position along the time scale is recorded.

At the same time, the pulse width at the position of second maximum is also recorded.

However, it is not necessary to record the echoes obtained from the top of the hole.

(ii) Placing the probe in the position for second maximum, determined as indicated in (i), it is rotated through successively increasing angles, its centre being kept fixed. For each angle, the echo amplitude is recorded.

The above procedure relates only to a combined transmit-receive probe. When separate probes are used, one transmit and one receive, the horizontal polar diagram is determined by keeping either the transmitting or receiving probe in a fixed position.

Appendix 3

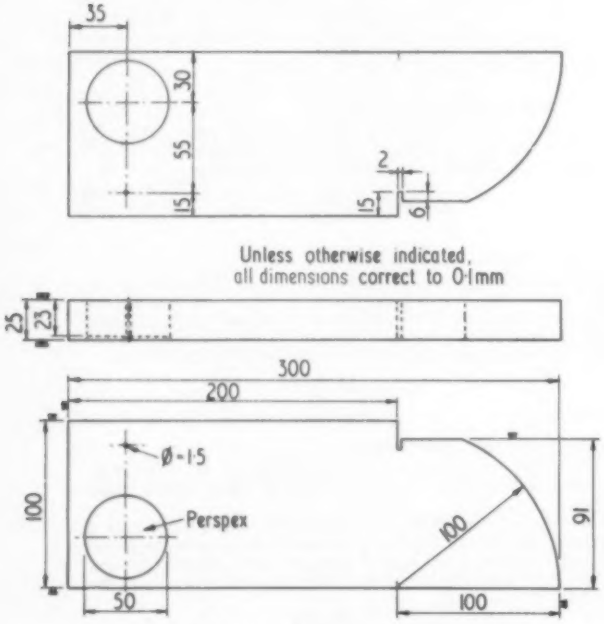
Note on Conclusions Drawn from Tests

By Mr. W. W. Campbell (United Kingdom)

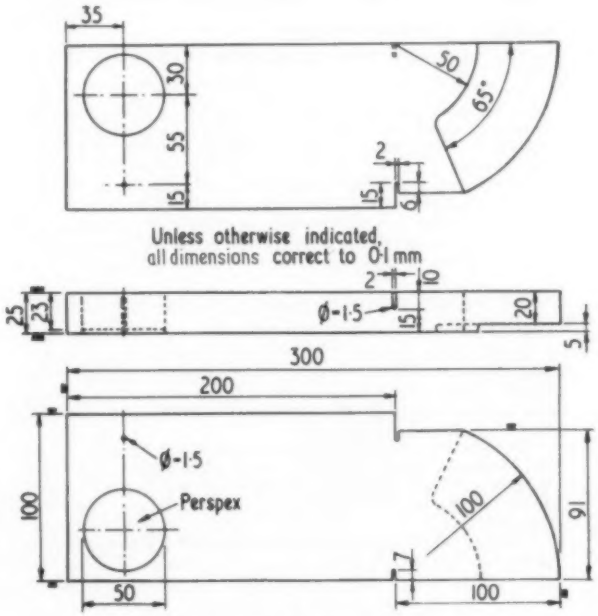
Arising out of the conclusions drawn from the tests, the following observations on certain salient features are submitted by the British delegation:

(1) The greater precision in determining the beam angle and index is imposed upon the apparatus by the nature of the test block and is therefore not necessarily desirable. The uncertainty shown by certain probes when reflecting from a corner is a relevant feature in their use for weld testing and ought to be revealed by the test block, as happens with the British block.

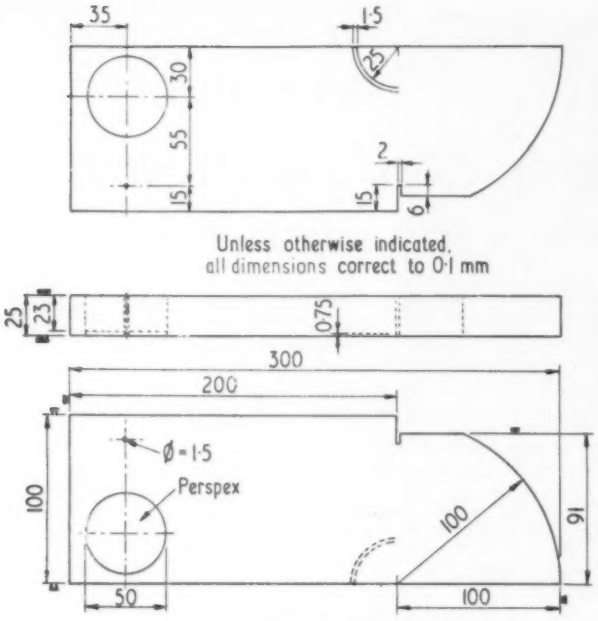
(2) Identical beam characteristics must not *a priori* be expected from two methods using different types of reflector. There is nothing surprising therefore about the difference in angle given by the two different blocks, nor about the agreement between the separate Danish determinations (based on a cylindrical reflector viewed from the edge of the plate) and



16—*Dimensions of recommended reference block*



17—*Additional reflecting surfaces*



18—*Additional reflecting surfaces*

the Dutch results, which are also based on a cylindrical reflector viewed from the edge of the plate.

(3) The British block was not designed for work involving longitudinal radiation. If calibration is wanted with such radiation a separate test piece can be used without encumbering the whole surface with the thickness necessary for a longitudinal calibration. It was suggested long ago by Mr. Gobus (United States), that more than one test piece might be needed and this has now been repeated by the Danish expert.

(4) The British workers prefer a calibrating procedure where the natural width of the beam is not liable to interference by reflection from two planes 25 mm apart. This does not correspond to the normal method of use either geometrically or in other ways. The British block allows the probes to be placed on relatively unlimited plane corresponding to the practical case.

(5) The British workers are most emphatic in believing double-probe testing to be especially appropriate in work with thick plates. Calibration facilities must therefore be provided for two probes; it is not sufficient to calibrate the probes of a combined transceiver separately for, apart from the general requirements of calibration under conditions of use, there are important cases where the technique will not permit single calibration. This is a point on which we must insist.

(6) A point of quite secondary importance is the question of trigonometrical tables. But, if beam characteristics are to be defined in polar co-ordinates, trigonometrical tables or their equivalents will be necessary eventually in determining the flaw position in Cartesian co-ordinates, and it is quite simple to provide convenient means of conversion. Beam characteristics, however, do not have to be defined in this way, and where they are defined in Cartesian or tangent terms no tables are needed with the British block.

Appendix 4

Description of the Reference Block, Recommended by the Commission, for the Control of Equipment for the Ultrasonic Examination of Welds

On the proposal of its Sub-Commission C *Ultrasonics*, Commission V of the IIW recommends the adoption of the following arrangements:

(1) In principle, the reference block should be in conformity with the indications shown in Figs. 16–18.

(2) No absolute recommendation is made regarding the position of the hole, which is $\frac{1}{16}$ in. (1·5 mm) in diameter

(3) For transverse wave calibration, use may be made of additional reflecting surfaces constituted by:
  (*a*) Either a saw-cut at zero-point (in conformity with Fig. 17)
  (*b*) or a saw-cut at zero-point and a curved surface of radius $R = 50$ mm (in conformity with Fig. 17)
  (*c*) or a circular saw-cut (in conformity with Fig. 18).

(4) The steel used for the production of the reference block should be as follows:
  (i) Killed open-hearth or electric mild steel,
  (ii) Normalized condition,
  (iii) Grain size Mc.Quaid-Ehn No. 8.

In regard to points 2 and 3, the choice between the various possibilities proposed is left to the judgement of the user.

LETTER TO THE EDITOR

THE PLASTICITY OF SOME OXIDES

In the course of recent work on pressure welding,* the suggestion was made that the pressure weldability of a metal or alloy was dependent on the ease of break-down of the oxide film during deformation. It was assumed that highly plastic films would deform easily without permitting metal-to-metal contact, whereas brittle films would break down when only a small amount of deformation was applied, and so would allow metal-to-metal contact.

In view of the lack of information on plasticity and the difficulties of measurement, it was assumed that hard films were brittle, and that soft films were plastic. This assumption has not been without its critics, and recently a method was found to check it.

The method used involved the stretching of scratch-brushed wires of various metals in a solution of common salt. The potential between the wire and a copper electrode was measured under increasing load. The potential stayed almost constant until a critical deformation was attained, when the potential increased suddenly. This was the point of film break-down and was found to be specific to the material being tested. The high voltage was maintained as long as the specimen was undergoing continuous deformation.

Oxide	*Critical Elongation, %*	*Hardness (D.P.N.)*
Al_2O_3	2	1800
Fe_3O_4	4	670
TiO_2	4	600
ZrO_2	5	670
SnO	7	380
ZnO	11	250
PbO	>12	23
Cu_2O	>26	160

The elongation required for film break-down was measured for a number of metals, and the results are given in the Table together with the hardness of the oxides. When these figures are plotted, a smooth curve is obtained. It seems, therefore, that hardness is a satisfactory criterion of plasticity, although the relationship is not linear.

R. F. TYLECOTE, C. F. WILFORD

Department of Metallurgy,
King's College
University of Durham

* R. F. Tylecote, D. Howd, J. E. Furmidge: *Brit. Welding J.*, 1958, vol. 5 pp.21–38.

SPRING MEETING 1960

Performance Record of the Thermatool High Frequency Resistance Welding Process

By L. A. Johnstone, F. J. Trotter, D.ENG., M.I.M.M., M.I.CHEM.E., *and H. F. a'Brassard*

A brief description is given of the method of high-frequency resistance welding developed by the New Rochelle Thermatool Corporation. The process has several advantages over orthodox low-frequency welding methods; three in particular being the ability to weld thin material without the danger of joint collapse, to weld quite heavily scaled or oxidized material, and to weld high carbon and alloyed steels. The same welding head can be employed for welding practically all commercial non-ferrous and light metals and their alloys.

Typical plants are described and operating records are given covering the full range of applications on ferrous, non-ferrous, light metals, rare metals and cable sheathing.

As a common feature of the widely diversified applications, the high quality and dependability of the weld are demonstrated by micrographs and by examples of flare, flattening, and pressure tests.

THE TITLE of this paper has been deliberately chosen to restrict its scope to the presentation of an account of practical achievement in some 50 plants in the United States, Canada, Mexico, and South America and in 24 plants so far licensed in Europe by the New Rochelle Thermatool Corporation, New Rochelle, N.Y., U.S.A. Only a broad outline of the process is given for the benefit of those who are not yet familiar with it from some of the several publications and Patent Specifications which for convenient reference are listed in a bibliography.

Principal Features of the Process

(1) The 450,000 c/sec current used is brought directly into the workpiece by sliding or rolling contacts, as distinct from induction by longitudinal or circumferential coils which induce heating in the metal to be welded.

(2) The task of applying a current of 1,000–2,000 amp by means of minute sliding contacts, having an area of only $\frac{1}{4} \times \frac{1}{16}$ in. has been successfully solved with a contact life of 40,000–600,000 ft of tubing, according to the surface of the strip to be welded.

(3) The h.f. current flows to a depth of merely a few thousandths of an inch and therefore only the surfaces of the approaching edges of the strip are heated. Because of the very high speed of welding, the heating of the metal remains indeed only 'skin deep', which accounts for the low power consumption and insignificant change in the crystal structure of the weld zone.

(4) Oxide layers, which are such a formidable obstacle in low-frequency welding, where the current has to crush through this barrier, act as conductors for the high-frequency current and, for example, hot-rolled steel without pickling or sand blasting is being readily welded in practice.

(5) Because, in contrast to the rotary electrode of the conventional low-frequency welders, only very slight contact pressure is required, thin-walled material well outside the conventional diameter/wall-thickness ratio can be welded.

(6) The same welding head can be used for welding mild steel, high carbon-manganese steels, stainless steels of the entire range, non-ferrous metals (including high conductivity copper and alloys), light metals and alloys, rare (atomic) metals and so on.

Manuscript received 4th February 1960.

Mr. Johnstone is Managing Director of Serck Tubes Ltd., Birmingham; Dr. Trotter manages the European business of the New Rochelle Thermatool Corporation; and Mr. a'Brassard is a Director of Elm Engineering Ltd., Aylesbury. 559

Capacity ratings

The commercial high-frequency welding units* have power ratings (measured at the output panel) of 60, 140, and 280 kW and their a.c. input capacities at line voltage are approximately 120, 280, and 560 kW respectively.

The attainable welding speeds are governed by the gauge of the strip, and are independent of the diameter of the tube except for very small diameters (Table I).

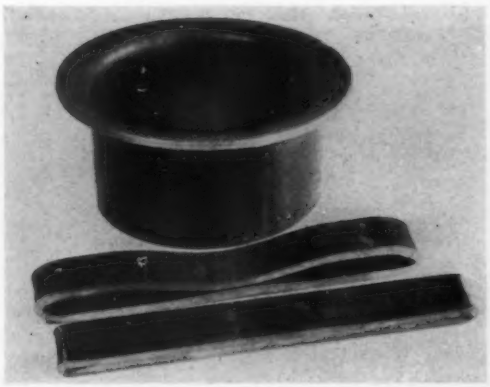
* In the context of this paper high-frequency welding refers specifically to the Thermatool process.

Table I

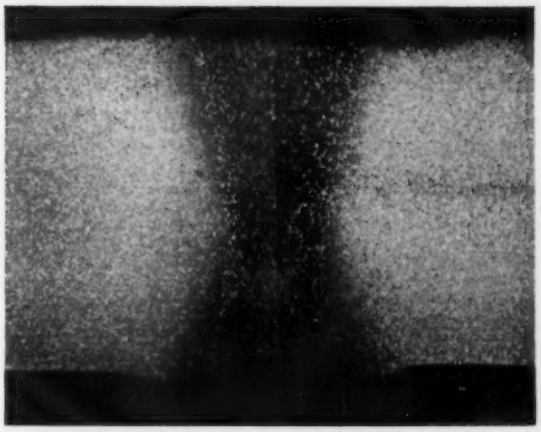
Attainable welding speeds of Thermatool installations

	Wall Thickness, in.	*Welding Speed, ft/min* 60 kW unit	140 kW unit
Mild Steel	0·03	300	over 400
	0·04	250	,, 400
	0·10	100	,, 200
	0·375		,, 20
Brass	0·03	300	
	0·06	200	
Aluminium	0·03	300	
	0·06	200	

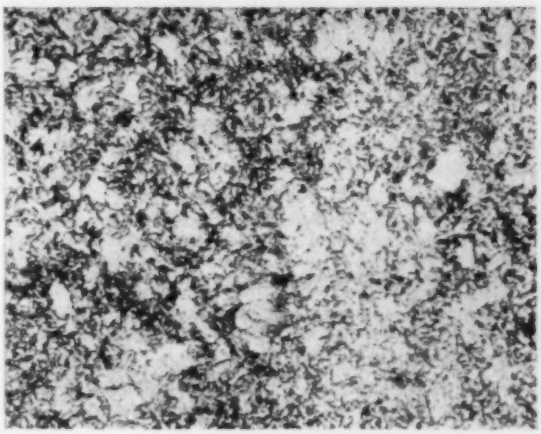
1—*Welding and scarfing section for small-diameter tubing*



(a)



(b)



(c)

2—*High-frequency-welded mild steel (0·23% C) tube 4½ in. o.d. × ⅛ in. wall thickness*: (a) *Flare and flattening test specimens;* (b) *macrograph of weld zone* ×10; (c) *micrograph of weld zone* ×200

Forming mills

As shown by Table I speeds of more than 300 ft/min are used on thin walled material so as to utilize fully the capacity of even the smallest, *i.e.*, 60 kW, unit. For such applications and also for welding comparatively soft non-ferrous and light metal strip or cable sheathing, the forming of the strip calls for a technique and equipment which, of necessity, must be different from that conventionally used in low-frequency welding of mild steel. Such forming machines, specially developed for the process, are now readily available from reputable engineering firms. Where speeds within the range of the low-frequency welding practice for mild steel are chosen, conventional or existing equipment can readily be adapted by changing the weld head and installing an adjustable weld table.

Applications

The main applications of the process can be conveniently divided into five groups:

(*a*) Ferrous metals
(*b*) Non-ferrous metals
(*c*) Light metals
(*d*) Rare metals
(*e*) Cable sheathing

Ferrous metals

Thin walled tubes (0·02–0·08 in.)

There is nothing revolutionary in this application except, perhaps, that the lower limit is well below that practicable with low-frequency welders. However, there are several advantages which cumulatively mark the high-frequency process as a distinct advance in the technique of steel tube welding (Fig. 1), even on this classical field of the low-frequency processes.[4,5] These advantages are:

(i) Higher speeds; hence increased production with the same complement of men, and lower power consumption:
Example: A 60 kW unit welding cold-rolled mild steel strip to 1 in. o.d. × 0·04 in. wall thickness tube at a rate of over 250 ft/min, at an average contact life of 80,000 ft. This compares favourably with even the best low-frequency installation of comparable rating.
(ii) Unexcelled quality of the weld (Fig. 6). The heat-affected zone rarely exceeds 0·06 in. and at the prevailing speeds and shallow depth of penetration of current (and heat by thermal conductivity) the crystal structure remains almost unchanged. The inner bead is very small and the internal surface of the tube is clean.
(iii) The human element is of less relevance, since fewer controlling factors have to be watched than in low-frequency welding.
(iv) More favourable diameter to wall-thickness ratio. Mild steel tubes of 2½ in. o.d. and 0·01 in. wall are being successfully lap welded with a standard 60 kW unit.
(v) A 60 kW installation, originally intended for other work, is now welding conduit tubing from hot-rolled steel. At least 12 installations operate on hot-rolled steel, scale on, with considerable savings in the cost of raw materials.
(vi) Alloyed steel strip can be welded in the same plant.
(vii) Similarly, the same plant will weld stainless steel strip of all varieties. One leading firm in the United States has, in fact, experimentally welded stainless steel varieties of 0·25% to 27% Cr, including the conventional series of Cr/Ni steels, without difficulty.
(viii) An enterprising tube maker, James Steel Company in Florida, has used a 60 kW unit for two years and welds galvanized mild-steel strip to tubes by continuously re-spraying the very narrow heat-affected zone after welding where the zinc has burnt off.

Heavy walled tubes (Fig. 2)

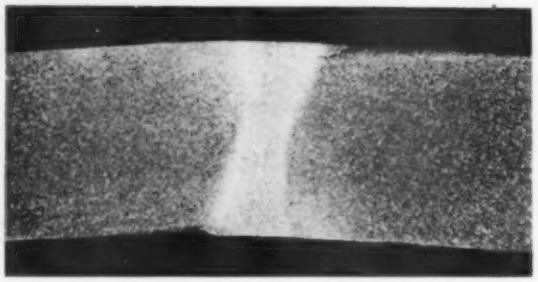
For strip greater than $\frac{5}{16}$ in. thick, up to $\frac{3}{4}$ in., 140 kW units are used; for still heavier duties 280 kW units. The following is a verbatim quotation from an unsolicited letter written by a user of a 140 kW unit:

"Some of the advantages to us are:
(1) Elimination of shot blasting of the edges for electrical contact, as required for low-frequency resistance welding
(2) Substitution of small sliding contacts to apply welding power to the seam instead of large rotating copper alloy electrodes
(3) The ability to weld metals other than steel
(4) Generally higher yields of prime pipe than usual with low-frequency welding
(5) Much higher weld quality generally and with much more latitude as to welding conditions than low frequency welding."

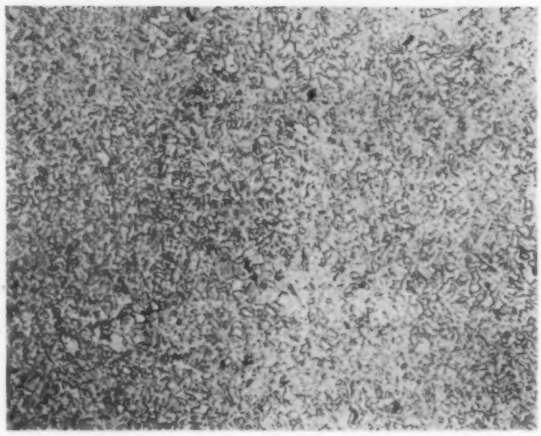
Another important tube mill in the United States returned the following comparative figures on prolonged production runs:

Overall yield (Low-frequency welding)	– tons out to tons in basis (includes losses from side trim, end crops, flattening tests and sub-standard pipe and faulty steel)	90%
	– footage out to footage in basis	95%
Overall yield (Thermatool welding)	– tons out to tons in (on same basis)	95%
	– footage out to footage in (on same basis)	99%

Both figures relate to mild steel pipe of up to 16 in. O.D. × ¼ in. wall.



(a)



(b)

3—*High-frequency-welded spiral tube, 16 in. o.d.* × ¾ *in. wall thickness*: (a) *Macrosection of joint;* (b) *micrograph of weld zone* ×100

4—*Macrograph of lap weld in spirally welded ferritic Cr-steel tube* ×20

When using hot-rolled steel, scale on, a contact life of between 40,000–50,000 ft has been reported in the production records. One installation in the United States was in effective production within hours of starting up, and has since produced about 5 million feet of pipe, mainly in the range $6\frac{5}{8}$–16 in. o.d. and 12 s.w.g.–$\frac{3}{8}$ in. wall thickness.

The A.P.I. testing procedure applied to the welded tubes has resulted in unqualified acceptance at values well in excess of those prescribed.[8]

It may be stated at this point that, if properly made, the high-frequency welds are strictly *forged* welds. This is possible because the opposing edges of the open-seam tube are heated by the current 'in space', *i.e.* the edges do not touch except at the apex of the V where they are squeezed together to form a forged weld. In all events, the effective temperature of the edges is kept below the melting point of the metal and within its plastic deformation range. The relevance of this technique will be made even more apparent in the next section dealing with non-ferrous metals.

The present, very distinct, trend among the leading tube mills in the United States and in Europe is to hail in the high-frequency welding process the advent of a new technique in the welding of heavy walled pipes *from alloyed steel strip*, thus being able to satisfy stricter specifications or to reduce wall thicknesses for the same requirements.

High-carbon, high-copper, and manganese steels are now being experimentally welded in commercial quantities on several 140 kW units in the Western hemisphere. Four units are now being installed in Europe which will be in operation during the first half of 1960 to implement such a programme. In all, 13 of these heavy units had been supplied by the end of 1959.

Spiral welding

The welding of large diameter pipes from narrow strip always was, and still is, a favourite target. The conventionally employed technique of using large sheets (produced by only a few well-equipped steelworks) forming them in costly hydraulic brakes and then making a metallurgically undesirable cast seam by submerged-arc welding methods at very low speeds demands an improved approach.

The spiral weld is generally about three times as long as a longitudinal weld for the same footage of pipe. The present severe limitation in welding speeds and the three-fold increased hazard of faults in a cast weld have undoubtedly retarded the wider use of this method of pipe production.

By applying the h.f. process as a novel tool, the following new facets appeared:

(*a*) With even the medium size 140 kW unit for, say, $\frac{5}{16}$ in. wall thickness, the guaranteed linear welding speed is 60 ft/min, *i.e.*, even when at one-third capacity, the production rate is still 20 ft/min, or about 15–20 times as much as is attainable by submerged-arc welding

(*b*) A forged weld of much superior and always dependable quality is made (Fig. 3).

(*c*) Hot-rolled strip with scale on can be used, of which there is generally a good and competitive supply.

(*d*) Alloyed varieties of strip can be selected, adding to the already superior strength of the spirally welded tube, or permitting thinner walls to be used.

At present there are four spiral mills in operation in the United States (one since 1957) welding hot-rolled steel. One is to start operation in Europe early this year and several are in advanced stages of design construction.

Commercial use is made in the United States of spirally-welded pipes of 12–24 in. o.d. and 0·07 in. wall thickness for piling purposes, using pickled hot-rolled steel.

A further commercial application of spirally-welded thin-walled tubes (0·01–0·1 in.) has been developed for air ducting, air conditioning, and for use in the fabrication of pre-stressed concrete members.

The linear welding speeds are a little less than those given for longitudinal seams.[14,16]

The first plant in Europe for the welding of thin-walled mild steel irrigation tubes will be in operation in April 1960.

Welding of segregated and laminated steels

Because the h.f. current travels on the surface and longitudinally and does not penetrate through the mass of material, irregularities such as are caused by segregation, or even laminated layers, in the strip do not represent serious obstacles to its passage.

An important tube mill in the United States is at present using up old stocks of laminated and segregated strip, which their low-frequency welder, now replaced by a 140 kW h.f. unit, was unable to deal with.

Versatility of performance

Low-frequency resistance welding is rather limited in its application, partly because the current travels mostly at right-angles to the weld axis. This phenomenon accounts for the troublesome need to 'juggle' with variables such as strength of current, surface conditions, resistivity, contact pressure, and contact resistance. The high-frequency current, on the other hand, is much more manoeuvrable.

Figure 5 gives a graphic demonstration of the many possible uses, some of them quite unique owing to the adaptability of the high-frequency current.

Generally, three types of weld exist: butt, lap, and mashed lap. All three are essentially forged welds and in no instance is the metal molten. The mashed lap weld is produced by rolling down the overlapping edges while the weld is still in the plastic state to form a joint which, to all intents and purposes, has the appearance of a butt weld, the thickness being the same as that of the strip.

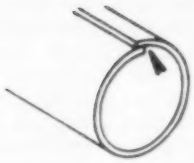
The macrograph in Fig. 4 shows clearly the compactness and soundness of the lap weld and there is similar crystal structure and uniformity in the mashed lap weld. This illustration shows the weld area of a tube which was spirally welded from ferritic Cr steel strip 2 in. wide and 0·015 in. thick.

Non-ferrous metals

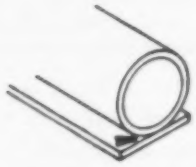
The authors are conscious of the privilege of being the first to present to the Institute of Welding a paper on the application of welding in a field which has hitherto been a jealously guarded preserve of the extrusion technique. Whilst the welding of non-ferrous metals in general, using a variety of processes,

1.
Conventional tubing continuously formed and butt welded, in diameters from ⅜ inch to 100 feet.

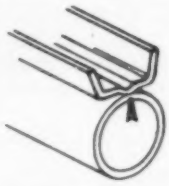
2.
Two formed halves made in press brake, continuously butt welded.



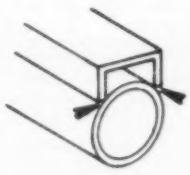
3.
Tube continuously lap or mashed lap welded. Typical use — containers, small or large diameters.



4.

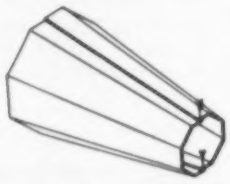


5.

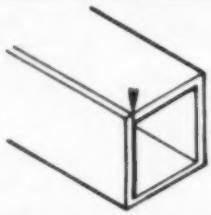


6.

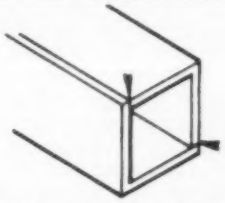
Tube continuously welded to a flat strip, channel or inverted channel.



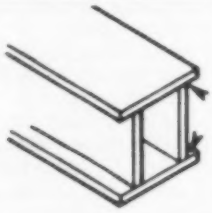
7.
Tapered tube — lap, butt or mashed lap welded made from one or two press formed shapes. Typical use — lamp posts.



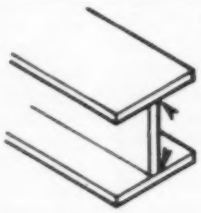
8.
Continuous welding corner of rectangular tube.



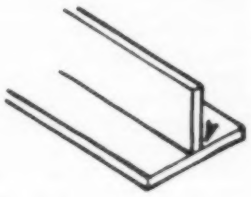
9.
Fabricating rectangular tube from angles — Two continuous welds made on drawbench, independently or together.



10.

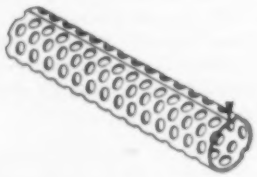


11.

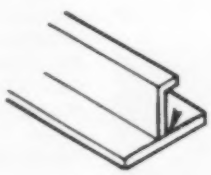


12.

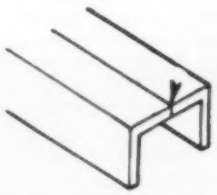
Fabrication of structural shapes from plate or strip by continuous welding.



13.
Perforated strip welded into tube for filters, well casings, mufflers, etc.

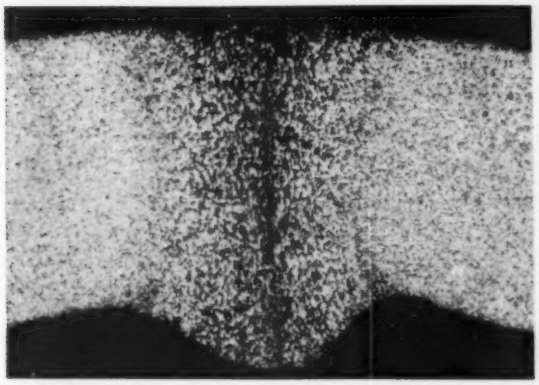


14.
Variation of T section welds.

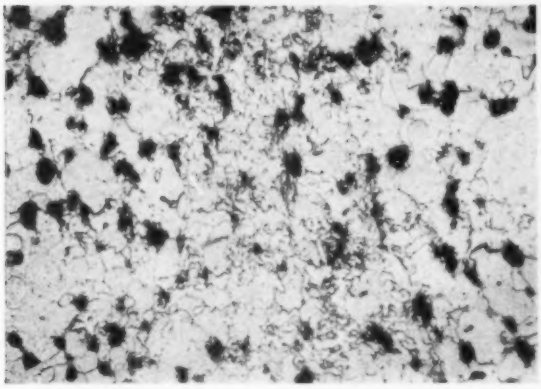


15.
Two angles welded to form a channel.

5—Examples of various applications of the high-frequency welding technique



6a—*Macrograph of weld in mild steel tube* ×20



6b—*Micrograph of weld area in mild steel tube* ×100

is of course a field excellently covered by the activities of the Institute, the authors believe it is for the first time that commercial production of conventional copper, brass, bronze, cupro-nickel etc. tubes by high-speed welding has been accomplished and reported upon. Clearly, the use of a welding technique which challenges the supremacy of seamless extruded and drawn non-ferrous tubes would be unthinkable and unrealistic on technical and economic grounds, unless the high-frequency resistance process offered some very tangible distinctions which rendered it a practical approach. The process does in fact offer such tangible distinctions. Basically, these are:

(*a*) Except in plants where ultra-modern and very costly extrusion presses are used, the dimensions of the extruded shells are much more substantial than the diameters and wall thicknesses of the ultimate products, necessitating repeated annealing and drawing operations. With welding, the width and gauge of the strip can be selected to yield a tube very closely matching the diameter and wall thickness of the desired end-product. As a practical rule, one annealing and at the most two drawing operations only are called for when processing a *welded* shell

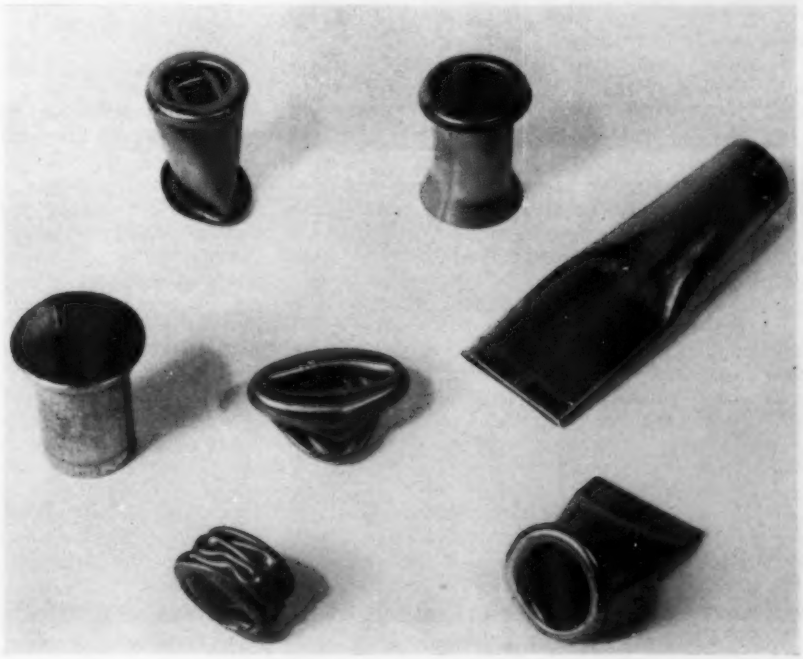
(*b*) The high rate of welding makes production rates of 150–300 ft/min of tubing quite feasible, and the time-consuming hand operations of repeated re-drawing of the shells is now being replaced by a fully mechanized continuous operation—a trend not yet adequately realized in most of the conventional non-ferrous mills in Europe

(*c*) Extremely accurate wall thicknesses and hence concentricity are possible by using precision rolled strip

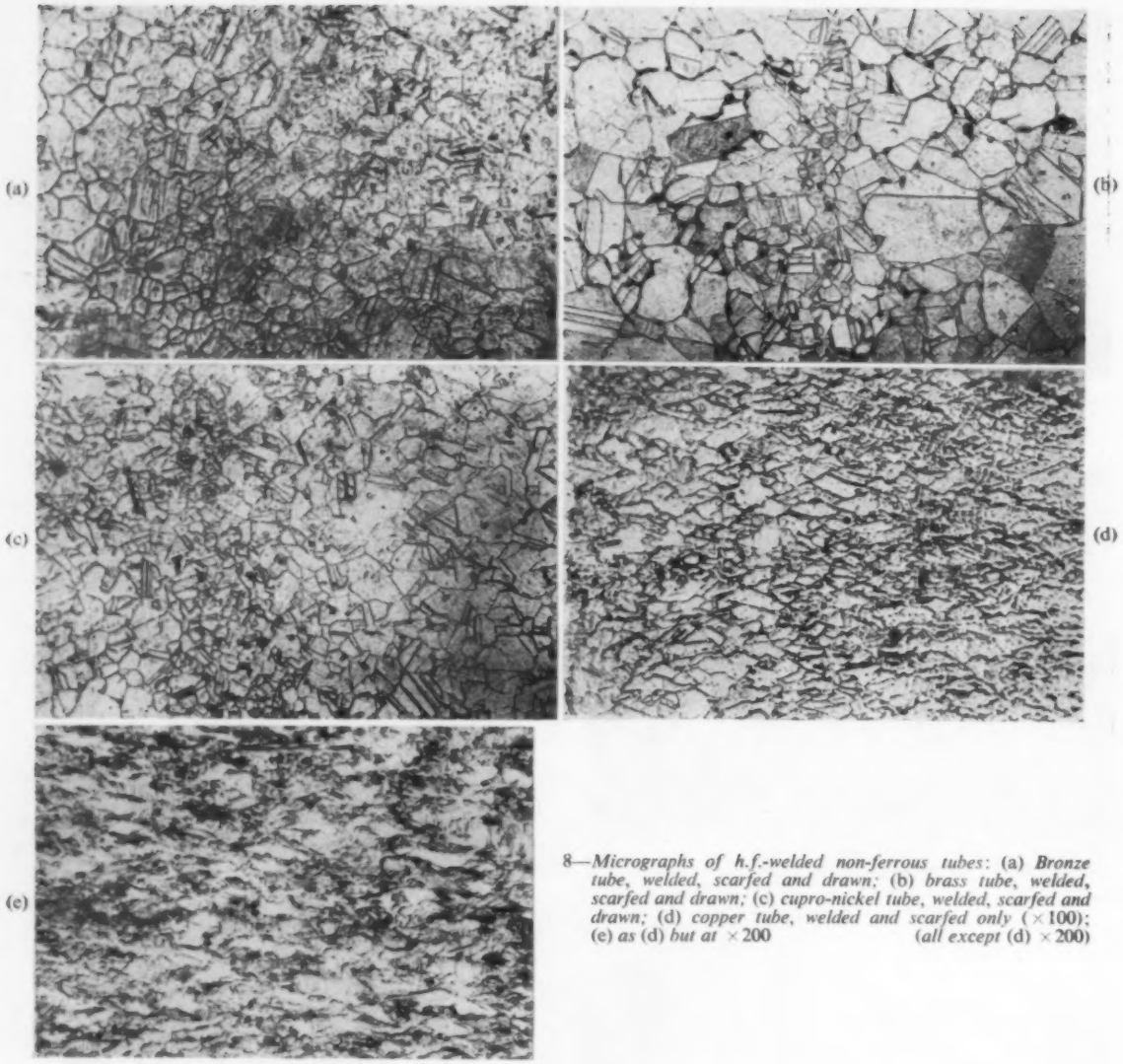
(*d*) In general, with the progress made during the last five years in rolling-mill design and operation, the conversion costs from ingot to strip have been reduced to a much greater extent than, by contrast, those of extrusion and cold drawing. The provision of cheap, narrow strip, especially where a uniform bulk demand exists, has now become a definite trend in the non-ferrous industry and favours, economically, the continuous welding of tubes.

(*e*) Very long tubes can be made by a coiling device.

The accomplished fact that almost all non-ferrous metals and alloys—and even high conductivity



7—*Test pieces of h.f.-welded brass tubes*



8—*Micrographs of h.f.-welded non-ferrous tubes*: (a) *Bronze tube, welded, scarfed and drawn;* (b) *brass tube, welded, scarfed and drawn;* (c) *cupro-nickel tube, welded, scarfed and drawn;* (d) *copper tube, welded and scarfed only* (×100); (e) *as* (d) *but at* ×200 (*all except* (d) ×200)

copper[9]—can be welded in actual production practice and at impressive speeds was, in itself, only one milestone in this new development. It still needed the resourcefulness and sustained effort of some progressive non-ferrous manufacturers in Britain and on the Continent to establish the *quality* of the welded product as being at least equal to the extruded and drawn counterpart. This point is of overriding relevance and should therefore be dealt with first.

As already explained, the high-frequency resistance welding process produces a forged weld and the heat-affected zone is kept to a minimum. The advantages of the old blacksmith type of forged weld over a cast weld, particularly for some of the heat-sensitive non-ferrous alloys, need no elaboration. By keeping the welding temperature down, not only are undesirable anomalies in crystal growth avoided, but volatilization of some metals can be kept at a trivial level. In fact, all copper and copper alloys can be, and are being welded in practice without the use of any protective atmosphere and this is done without producing any oxide inclusions in the weld.

The proof of this statement is, of course, given by the physical tests and micrographs. Test specimens taken from production are currently examined by rigid flare, expansion, bending, and flattening tests (Fig. 7), and in the case of technical applications, as distinct from decorative ones, exacting hydraulic and plug tests are also routine procedure. In all instances, the welded products stand up to the tests prescribed by the relevant Standard Specifications and practical requirements for solid drawn tubes, with the added advantage of perfectly uniform wall thickness, which represents an additional safety factor for design purposes.

As is shown by typical micrographs (Fig. 8), the

Table II

Conditions for h.f. welding of non-ferrous metals

Weld Size, in.	*Speed, ft/min*	*Material*	*Number of Drawing Operations*	*Final Tube Size, in.*	*Pressure Test, lb/sq.in.*	*Drift Test*
1 ×0·036	200	63/37 Brass	2	0·930×0·022	2,000	Satisfactory
1⅛×0·048	125	63/37 Brass	2	1×0·036	2,500	Satisfactory
1⅛×0·048	140	70/30 Brass	1	1¼×0·036	2,500	Satisfactory
1 ×0·032	260	70/30 Brass	1	0·875×0·024	2,000	Satisfactory
¾ ×0·028	200	Cupro-Nickel	3	0·55×0·020	—	Satisfactory

width of the weld zone is, as a rule, less than 25% of the thickness of the strip and no cast weld or oxide inclusions or pores are discernible. High-conductivity copper tubes, even in the 'as welded' condition, barely show a coarsening of the crystal structure, and in all instances a single annealing and re-drawing operation completely normalizes the metal. The micrographs show that the finished product cannot be distinguished from a solid-drawn tube. Complete homogenization takes place and this, of course, accounts for the superior mechanical properties.

The outer bead, which does not as a rule protrude more than 0·02 in., is scarfed off in a continuous operation as the tube leaves the welding contacts. In a similar manner, the inner bead can also be scarfed off or, if small, left on and later removed by the first drawing operation. In either case, the appearance, polish, etc., of the finished tube is up to the most exacting standards of the trade.

Whilst, of course, a great deal of hard-earned 'know-how' is needed to adjust conditions to weld the wide variety of commercial non-ferrous alloys, there is basically no difference in the technique of welding pure copper, brasses and all grades of bronzes (Table II).

The economic aspects of the process provide a very complex picture. The relevant factors are:

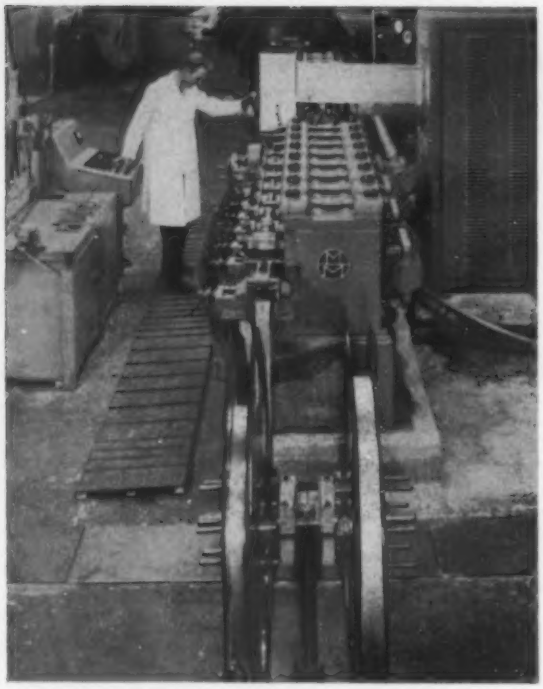
(i) Cost of strip
(ii) Diameter of tube
(iii) Wall thickness of tube
(iv) Type of metal or alloy.

It is obvious that, as with many 'revolutionary' processes, the established techniques are rarely completely displaced. So, too, with the h.f. welding process. There exists a line beneath which it offers advantages and above which only marginal, or no advantages at all can be claimed in comparison with the extrusion and drawing processes. In arriving at a valid comparison, it has to be assumed that the extrusion and drawing plant is of the most modern design and that it is being operated efficiently. With out-of-date equipment, the comparison comes out much more categorically in favour of the modern, streamlined production method of the welding process.

On the above premises, countless detailed works calculations seem to indicate that in the field of diameters below 1¼ in. and wall thicknesses below 0·06 in. for brass and copper, the process offers distinct economic advantages provided, of course, that the diameter and wall thickness of the weld product are so selected that they closely approach those of the desired final product: this can readily be done by specifying appropriate strip dimensions. Equally, in the diameter range in excess of, say, 2 in., particularly when the end-product is thin walled, the process offers very distinct advantages. Generally, the more difficult it is to extrude the metal or alloy and the more laborious it is to re-draw the shells, the more the welding process comes into its own because, as a rule, these difficult alloys are much easier to roll than to extrude and re-draw. Typical cases are bronzes and cupro-nickel: in these instances the areas of economic advantages outlined in the foregoing become considerably enlarged.

In computing production costs, respective scrap risings which have to be re-treated must naturally be taken into consideration. As a rule, they are already

9—*Typical high-frequency resistance welding plant for non-ferrous tubes*



10—*High-frequency welding plant for aluminium alloy tube*

partly absorbed in the cost of the strip and reduced on account of the greater length of the feed to the draw-benches.

An interesting feature of the welding process is the comparative ease with which dimensional changes, particularly in wall thicknesses, can be accommodated. Specially designed forming mills effectively cater for this specific feature of non-ferrous applications of the process. The often very high rate of production would be sensitively limited by the comparatively small weight of the coils produced by the rolling mills and to ensure continuous high-rate utilization of the 'racehorse'—which is perhaps an apt description of the high-frequency welder—coils of often 6–9 ft dia. are made up by butt welding together the ends of the coils.

The welded tube can be produced in any desired length and therefore it lends itself to continuous re-drawing, as distinct from drawing finite lengths of extruded shells, or bull-block drawing of long coils for subsequent distribution to finishing benches or straightening and cutting-off equipment.

A typical high frequency welding plant for non-ferrous tubes is illustrated in Fig. 9.

11—*Seam guide, contacts, and squeeze rolls*

Light metals

A great deal of what has been said in the preceding section about non-ferrous metals fully applies to the light metals. There is, however, one major distinction; that a very substantial tonnage of the welded aluminium and aluminium alloy tubes can be, and is being, sold and used by a growing number of industries in the 'as welded' condition. Except for scarfing, sizing, and external polishing, which are all steps of a continuous operation, the tubes are automatically cut to length and used without further treatment, such as re-drawing.

The tube manufacturing plant at Elm Engineering Ltd., the first of its kind installed in the United Kingdom, consists of two major components, the high-speed tube forming mill and the Thermatool high-frequency resistance welding unit (Fig. 10).

The patented Thermatool welding head (Fig. 11) is identical with those used for welding steel or non-ferrous metals and has a h.f. transformer with an input of approximately 3000 kVA and 50 kW. The secondary of this transformer feeds current at about 100 V to a pair of water-cooled leads which take it down to the two contacts. These contacts, which are water cooled, rest on top of the tube just in front of the weld pressure rolls. Each contact block can be quickly replaced, although their service life when welding aluminium is quite considerable; dependent on the temper of the strip, about 100,000 feet. The welding head itself is mounted on an adjustable device, which permits the contacts to be brought down on the tube just in front of the squeeze rolls with accurately adjustable, but always modest, pressure.

The actual sequence of operations is for the aluminium alloy strip to be fed into the mill from a large coil holder mounted on a rotatable stand. This stand holds two coils, one on either side, so that re-loading can take place while one reel is being fed to the mill.

The strip passes through a series of forming rolls, then it proceeds to the seam guide which predetermines the weld gap. Next comes the welding head supplying the h.f. current closely followed by the squeeze rolls. The tube then passes to two scarfing tools which remove the external flash. Sizing and straightening is carried out by four roll stages. Finally, the flying shears cut the tube into suitable lengths.

The welding speed varies with the thickness of the strip. A typical example of operating conditions is:

¾–1 in. o.d., 18 s.w.g., NS.4 alloy strip currently welded at 300–325 ft/min

The particular captive market for which these tubes were designed was one which had consumed tremendous quantities of standard tubing, so far as both diameter and gauge were concerned.

There has been a general standardization of specification, as a result of which certain minimum mechanical properties were required.

The sizes used were either extruded or extruded-drawn tubes for applications in the size range $1\frac{1}{2}$, $1\frac{1}{4}$, 1, $\frac{7}{8}$, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{2}$ in. all in 14, 16, 18, and 20 s.w.g. The larger sizes were used for masts to carry substantial television aerial arrays, sometimes at considerable heights and frequently fixed to ancient chimneys where the need for light weight, but strong tubes, was obvious and for aluminium alloys because of their resistance to rust and corrosion.

The advantage of the high-frequency welded aluminium alloy tube was to use the tube in its 'as manufactured' condition.

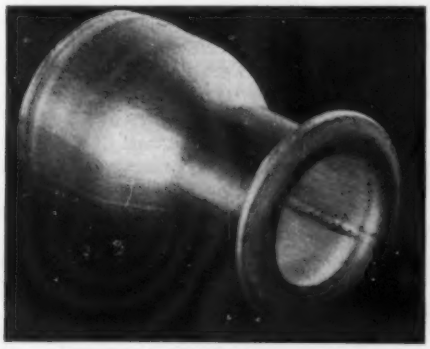
A new and interesting development from this field was the utilization of the $\frac{3}{4} \times 0{\cdot}048$ in. (and other sizes) tube produced by this process for the construction of folding garden tubular furniture. Here, an additional process followed the cutting to length, namely the mechanical polishing of the aluminium tube.

The tubing was also subjected to test by anodizing or by electro or chemical brightening. In these cases the welding was found in no way to be detrimental, and left no significant line on the tube that would cause its rejection on inspection.

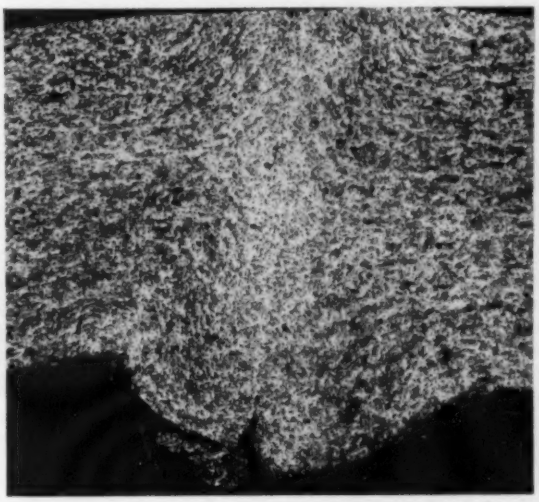
The material used throughout was aluminium alloy strip produced to BS.1470, which was readily available from four major suppliers in this country.

There were some limitations, in that it was important to have as heavy a coil as possible, the greatest weight available being about 100 lb per inch of width. Arrangements are being made for making up larger coils by butt welding the ends of the small coils. This is standard practice in other fields of application, *viz.*, steel, brass, copper, etc.

The mechanical properties of the strip used for the construction of tubing were known, of course, and it was found, by a series of tests carried out by the Fulmer Research Institute and also by the companies supplying the strip, that in all cases where non-heat-treatable strip was used mechanical properties were enhanced by the cold working of the forming mill.



12—*Test piece of h.f.-welded aluminium alloy tube*



13—*Transverse section through welded aluminium alloy (NS.4) tube* ×50

Thus, by starting with even a half-hard or a hard-temper material it was possible to increase further the mechanical properties so that the high-frequency welded tube had properties (proof and U.T.S.) equivalent to a heat-treated conventionally produced tube. These tests were carried out in accordance with BS.L100. Further tests showed that when the tube was coned to 30° over 25% increase in diameter could be realized without failure occurring (Fig. 12). Tubing could be satisfactorily bent with or without mandrels to between two and two and a half times the outside diameter of the tube.

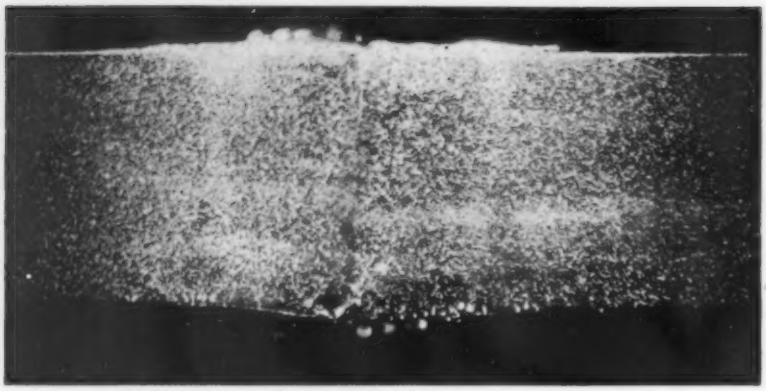
Practical experience in both drilling and piercing the tube deliberately at the weld and also closely adjacent to it, proved to the manufacturer's satisfaction that the weld area was as strong as the rest of the tube.

Micro-examination of the weld area achieved by the high-frequency method showed it to be of excellent quality, completely homogeneous and free from oxide inclusions (Fig. 13).

Some of the tube was re-drawn so as to test the result of reducing the wall thickness and outside diameter of a welded tube. This test helped to prove that the tube was completely homogeneous (in fact the internal scarf disappeared after the second or third pass) and that the welded, re-drawn tubes were indistinguishable in appearance and quality from extruded and drawn tubes. Today, some twelve months after production was first commencing, and with an output of many thousands of miles of tubes, the number of returns and complaints for 'non-welded' tubes has been negligible.

With properly maintained equipment, using controlled raw material, it has been our experience that 'as manufactured' aluminium alloy tubes produced by the Thermatool process are admirably suited as a direct replacement for conventionally produced tube.

Needless to say, the very substantial price differential existing between strip and tube, and the purely nominal welding costs at practicable high speeds, accounts for a growing expansion of the market. This



14—*Weld zone of h.f.-welded zirconium* ×10

consideration particularly applies to the welding of high-strength light-metal strip. The extrusion of these alloys is slow and costly, whereas rolling them to strip is comparatively cheap. There is no perceptible difference in operating the welding machine on pure aluminium or on aluminium alloy strip.

The spectacular increase in the use of welded tubes is shown by the Returns for the first six months of 1959 of the U.S. Department of Commerce, listed in Table III.

Rare metals

This performance record would be incomplete without a brief reference to the successful application of the process in the field of rare metals as used in the nuclear energy industry. The work carried out in this direction is, of necessity, largely confidential, but it is expected that in the near future some information will appear in the technical press.

A relevant piece of information has recently been de-classified and published in the United States (A.E.C. Report TID-7546) on the satisfactory use of the process for welding Zircaloy tubing and the welding of spiral ribs to such tubing. The same welding head has been used to join longitudinal and spiral fins to the tube. As a major advantage of the process it is stated that "the tubing is not heated sufficiently to cause warping or to affect its corrosion resistance". The uniform grain structure (Fig. 14) is a further distinct advantage.

One of the leading firms in the atomic metal field in Britain has been experimentally operating a high-frequency resistance welding unit for the past two years and it is hoped that in due course some of the results of their widespread investigations will be made public.

Generally, when welding rare metals such as zirconium,[15, 17] titanium, tantalum, or berylium, a protective gas atmosphere is used. This can easily be arranged around the small contact assembly and does not cause any complication in the operation of the plant. No other special precautions are needed.

Table III

Increase in use of welded aluminium alloy tubes

	Millions of Pounds		
	1st Half 1958	*1st Half 1959*	*Percent Increase*
Net shipments of welded aluminium tube by six fabricators	12·2	20·0	63·2
Drawn tube	33·7	45·0	33·6
Latest available figure for July 1959	2,597,000 lb welded tube 5,976,000 lb drawn tube		

Cable sheathing

This section has been included for the sake of completeness and because it is expected that welding will play an increasingly important role in the manufacture of cables. It also emphasizes the dependability of the high-frequency weld. In this application any failure, even a microscopic pinhole, is fatal and cannot be cured; it would involve the scrapping of the entire cable, which represents several times the cost of the sheathing itself.

During the past few years, the trend in cable manufacture has moved distinctly in the direction of using aluminium, mild steel, and copper sheathing, partly for electrical and partly for mechanical reasons. The simultaneous use of a metallic sheath, putting it to use as a neutral conductor, and the greater mechanical strength of the aluminium and mild steel with a more favourable weight ratio than is possible with the traditional lead sheath, have all stimulated this development.

Initially, the choice of metals was rather limited. Pure aluminium sheath has been extruded around power and telecommunication cables, but this method suffered from a number of drawbacks, such as lack of uniformity in wall thickness which caused faulty reception when used for television cables, difficulties in continuous extrusion without pores at the transition from one billet to the other, high cost of the powerful extrusion presses, and cooling problems. Moreover, this method is not practicable with mild steel, stainless steel, and aluminium alloys. Accordingly, welding had to be introduced if these metals were to be used. Of them, only mild steel responded to low-frequency resistance welding, whereas high-frequency induction welding of the other metals causes fluctuations in the applied power and excessive heating of the cable core. Argonarc welding proved to be quite a versatile method, but has so far had only a limited success in practice.

probably owing to low welding speeds and high costs.

The high-frequency resistance welding method was first used for cable sheathing in Europe, and at present two leading cable works in Sweden and France use it. Two further units in Europe have been installed but are not yet in full production.

The operational requirements are very different from those of tube welding, and the process had to be adapted to the special needs of the cable industry. Speeds of only 60–80 ft/min are used as a rule, *i.e.*, several times those possible with argonarc welding but still much below the practicable speeds when welding the same metal to tubes. The welds are made without a protective atmosphere and the sheath is formed and welded around the cable *in situ*, both moving continuously past the contacts.

As with tube welding, the heat-affected zone is localized and the paper/plastic-insulated or oil-impregnated cable remains completely unaffected by the heat. In fact, on leaving the squeeze rolls of the welder the sheathed cable can be held in the un-gloved hand.

Many months of strict testing under vacuum, which has to be held for long periods, and also under air pressure applied while the cable is submerged in water to show up any minute pores, has proved the complete dependability of the weld to the satisfaction of this most critical group of users.

As with the tube welding of non-ferrous and light metals, micrographs show a completely uniform, fine-grained structure in contrast with the argonarc welded seam which, being a cast weld, shows a marked coarsening of the grain structure in the weld area.

One of the most outstanding developments in this new and widening field of welding has been the successful creation of a sheath-forming mill, designed by a leading Swedish cable works, and using the high-frequency process. The extremely wide range of diameters and wall thicknesses specified for cable sheathing, and the resulting comparatively very frequent changes in tool settings, obviously call for a much more flexible technique than is customary in tube welding.

Whilst extruded sheath as a rule closely fits the cable, the welded sheath is deliberately fitted to leave a small annular air space. The welded sheath is subsequently corrugated, *i.e.*, helical or parallel grooves are impressed upon the sheath which will thus tightly grip the cable. The severe stress imposed on the weld by the corrugation process and also the repeated bending during coiling, un-coiling, and laying of the cable gives further proof of the high quality of the weld. The corrugated cable has the very distinct advantage of being much more flexible and can be bent round a much smaller radius (5 to 10 times the cable diameter) than is possible with the old-fashioned lead-sheathed type of cable.

Details of this interesting and novel application of the h.f. resistance welding technique are clearly the province of cable specialists. A comprehensive account of developments in this field will be presented during the Summer of 1960 to one of the learned Electrical Societies, and that paper will no doubt also contain a great deal of interesting information on the welding technique itself. It would therefore be rather improper to take this part out of its rightful context.

BIBLIOGRAPHY

1. W. C. RUDD: Third Annual Midwest Welding Conference, Chicago Section, American Welding Society, 30 Jan. 1957.
2. J. J. OBRZUT: *Iron Age*, 1957, vol. 179, 6 June.
3. W. C. RUDD: *Welding J.*, 1957, vol. 36, 703–707.
4. Editorial: *American Metal Market*, 10 Oct., 1957.
5. Editorial: *Steel*, 21 Oct., 1957.
6. Editorial: *American Machinist*, 24 Feb., 1958.
7. W. C. RUDD: *Metal Progress*, 1958, vol. 73, p. 82.
8. Editorial: *Western Metalworking*, Oct., 1958.
9. Editorial: *American Metal Market*, 8 Jan., 1959.
10. Editorial: *Business Week*, 7 March, 1959.
11. Editorial: *Metal Industry*, 7 March, 1959.
12. C. W. J. VERNON: *Welding Met.\Feb.*, 1959, vol. 27, pp. 80–82.
13. D. G. OSTERER: *Modern Metals*, 1959, Aug.
14. Editorial: *Iron Age*, 6 Aug., 1959.
15. Editorial: *Nucleonics Magazine*, Nov. 1959.
16. Editorial: *Iron & Steel Engineer*, Nov. 1959.
17. Editorial: *Electrified Industry*, Dec., 1959.
18. R. J. ALLEN: *Product Eng.*, 1960, Jan.
19. *Reynolds Aluminium Digest*, Oct. & Nov., 1959.
20. British Patent 748,528
21. British Patent 772,279.
22. British Patent 772,398.

LETTER TO THE EDITOR

STRESSES IN CYLINDRICAL VESSELS

The BWRA report by R. T. Rose* makes a very valuable theoretical contribution to the problem of local heat-treatment, and will therefore be widely read.

The synopsis, however, could give an incorrect impression to some readers, and it therefore seems appropriate to draw attention to the following points.

The synopsis states: "There is a danger that the local heating may itself result in the appearance of residual stress", but on reading the article, it is found that the theoretical treatment deals solely with the residual stresses likely to arise from such local treatment.

Nothing is said in the article about "danger", nor about the net effect of superimposing one system of residual stress upon another. Such superimposition does not, of course, always result in a worsening of the conditions. For example, it is conceivable that by superimposing a *reversed* system of residual stresses the net result would be no residual stress at all. Also, it is easy to conceive a treatment that would have the effect of spreading and reducing the peaks of the existing residual stress system.

A further very important point is that the article does not discuss whether the supposed "danger" of introducing residual stresses may not be outweighed by the improvement in metallurgical conditions brought about by the heat-treatment. These are matters which are by no means resolved, but are at present under active study.

G. M. BOYD

Lloyd's Register of Shipping
71 Fenchurch Street,
London E.C.3

* R. T. Rose: *Brit. Welding J.*, 1960, vol. 7, pp. 19–21.

Welding
RESEARCH

SYMPOSIUM ON FATIGUE OF WELDED STRUCTURES

Factors Influencing the Fatigue Behaviour of Welded Aluminium

By J. E. Tomlinson, B.SC., A.I.M., *and J. L. Wood*, B.SC.

An outline is given of the general fatigue behaviour of aluminium alloys used in welded construction, and published work is reviewed to illustrate the factors influencing the behaviour of welded connections. For a given material the performance of as-welded joints depends mainly on configuration and bead profile. Internal defects are of particular importance in butts where reinforcement is removed. Current heat-treatable alloys have as-welded fatigue properties similar to those of the stronger non-heat-treatable materials. Methods of improving fatigue performance under some conditions of service by readjustment or removal of unfavourable internal stresses show considerable promise.

Introduction

WHILE there is extensive literature recording the fatigue behaviour of the high-strength heat-treatable aluminium alloys in relation to the requirements of the Aircraft Industry, there are comparatively few data on the performance of pure aluminium and the medium-strength non-heat-treatable alloys, such as are employed in the Chemical Industry and for transport and structural applications. Furthermore, the information concerning the performance of joints refers principally to riveted, bolted, plastic bonded, and spot welded connections rather than to those produced by fusion welding.

Since the first paper dealing with the fatigue behaviour of fusion welded aluminium alloys was published in 1947[1] a total of only a dozen such papers has appeared. In this period fusion welding has been developed into an efficient method of jointing aluminium through the introduction of the inert-gas shielded-arc processes. As a result, large welded aluminium structures are being considered or are already in use in many fields of engineering, and the need for fatigue data is becoming more widely appreciated. It is the purpose of this paper to outline the general fatigue behaviour of aluminium alloys that are used in welded construction, to summarize existing information on the fatigue strength levels which are to be expected of welds and the factors that are at play, and to draw attention to the further information that is required.

Materials and metallurgical effects of welding

Before embarking upon a review of the present state of knowledge of this subject, it may be helpful to examine briefly the differences between the types of alloys likely to be used in structural applications and to note the effect of the various welding processes upon the metallurgical condition and the static mechanical properties of each type.

Table I lists the materials most likely to be employed in welded structures. Aluminium of 99·5% and 99·0% purity and NS.3 are employed for chemical plant and certain nuclear engineering equipment, in which fatigue conditions can arise. Alloys NP.4, NP.5/6 and HP.30 are the most widely used in general engineering construction. Pure aluminium and alloys containing manganese and magnesium are described as non-heat-treatable because they can be hardened only by cold

Paper to be presented at a Symposium on Fatigue of Welded Structures, to be held at Cambridge University on 29th March–1st April 1960.
The authors are with the British Aluminium Co. Ltd.

Table I

Minimum and typical mechanical properties of some of the aluminium alloys commonly employed in welded structures

Alloy Group	*British Standard Alloy Designation*	*Alloy Type*	*Temper or Condition*	*Minimum Mechanical Properties** 0·1% Proof Stress, tons/sq.in.		Tensile Stress, tons/sq.in.		Shear Strength‡	Elong. on 2 in, %	†Typical Fatigue Strength, tons/sq.in.	*Typical Tensile Strength of Mig or Tig Butt Welds, tons/sq.in.*	
Non-Heat-Treatable	S1B	99·5% pure aluminium	O	—	(2·1)	4·5	(5·2)	(4·1)	30 (47)	±2·5	4·75	
			½H	—	(6·2)	6·5	(7·2)	(4·8)	8 (13)	±3·5		
	S1C	99·0% pure aluminium	O	—	(2·2)	5·0	(5·8)	(4·5)	30 (43)	±2·5	4·75	
			½H	—	(6·8)	7·0	(7·8)	(5·2)	7 (12)	±3·5		
	NS.3	Aluminium 1·2% Manganese	O	—	(3·8)	6·0	(7·0)	(5·4)	30 (40)	±3·5	7·0	
			½H	—	(8·6)	9·0	(10·0)	(6·5)	7 (11)	±4·5		
	NP.4	Aluminium 2¼% Magnesium	O	—	(5·0)	—	(11·0)	(8·2)	— (28)	±6·0	12·0	
			M	—	(6·0)	12·0	(13·0)	(8·6)	12 (20)	±8·0		
	NS6 and NP5/6	Aluminium 5% Magnesium	O	7·0	(9·0)	17·0	(18·5)	(11·5)	18 (26)	±8·0	17·0	
			M	8·0	(10·0)	17·0	(19·0)	(12·5)	12 (20)	±9·0		
Heat Treatable	HP.30	Aluminium 0·7% Magnesium 1·0% Silicon 0·5% Manganese	W	7·0	(9·5)	13·0	(16·0)	(11·3)	15 (21)	±7·0	*Mig* 13	*Tig* 12
			WP	15·0	(17·5)	19·0	(20·5)	(13·4)	8 (12)	±8·0		

* Typical properties in brackets † Based on flexure tests at 50×10^6 cycles ‡ No specified minimum value

Nomenclature System

Material form
S = Sheet (up to 0·252 in. thick)
E = Extruded sections
P = Plate
G = Wire

Material type
N = Non-heat-treatable
H = Heat-treatable

Material condition
O = Annealed
M = As manufactured
½H = Half Hard
W = Solution treated—naturally aged
WP = Solution treated—artificially aged

rolling and similar working operations. Whilst the work-hardened tempers of pure aluminium and the non-heat-treatable alloys are stronger, though less ductile, than annealed metal, they have almost the same static strength when welded because of the annealing effect of the heat of welding. For all the non-heat-treatable materials listed in Table I, other than NP.4, it is usual to employ filler or electrode wire of parent metal composition. Hence, with modern fusion welding processes giving sound deposits, the static tensile efficiency of butt joints in annealed materials can be expected to be close to 100%, though tensile failures in specimens tested with reinforcement removed will generally occur either in, or at the edge of the weld metal. For N.4 alloy, it is usual to employ a filler or electrode wire containing a higher magnesium content (NG.6 Al–5% Mg) to remove the risk of weld cracking during solidification, and with this practice the tensile efficiency of butt joints in annealed material will be 100%; the failure of welds tested in tension with reinforcement removed being outside the weld metal.

The remaining alloy listed in Table I, HP.30, is of the heat-treatable class. For this material, heat-treatment comprises in the first place a solution treatment in the range 520–540°C., followed by quenching in cold water to dissolve hardening constituents and to retain them in solid solution. Hardening then takes place during natural ageing at ambient temperature for a few days or, more intensely, as the result of artificial ageing at 170–200°C. for a few hours. Because H.30 is susceptible to hot cracking, it is usual to employ either the Al–5% Mg alloy (NG.6) or the Al–5% Si alloy (NG.21) for filler metal; in either case the weld metal will have a structure and mechanical properties differing from those of the parent material. With heat-treatable alloys such as H.30 the heat of welding produces notable changes in the structure and properties of material adjacent to the weld. The weld metal usually cools rapidly enough after welding to be effectively in the solution-treated and quenched condition, and will harden subsequently both at ambient temperature and on artificial ageing. Immediately adjacent to the weld is a narrow 'over-heated' zone where partial melting takes place. In this and the next zone, the temperatures attained, ranging from 590° down to 300°C., are high enough to dissolve some of the soluble constituents, which are partially retained in solid solution if the subsequent rate of cooling is sufficiently rapid. In the next zone, where temperatures in the range 300–200°C. are reached, heavy precipitation of soluble constituents occurs (over-ageing) causing marked softening; beyond it, where the temperature has not exceeded 200°C., the parent material is not affected by the welding operation. In tensile tests of manually welded butt joints made with Al–5% Si filler and with reinforcement removed, failure will often occur in the over-aged zone. It will take place in the weld metal only if the weld is seriously defective or if the heat input in welding has been remarkably low. These effects are described in more detail in ref. 2.

Interest has recently been aroused in heat-treatable alloys based on the Al–Zn–Mg system. These materials, which generally contain from 3–5% Zn and 1–2% Mg, with minor additions of Mn and Cr, are solution treated at temperatures in the range 350–400°C. They age slowly at ambient temperature, taking up to three months to reach their ultimate hardness but can be artificially aged at 80°C. for a few days. On welding, softening takes place throughout a fairly wide band of metal on both sides of the joint, but on subsequent natural or artificial ageing almost full recovery of hardness takes place. Thus tensile specimens tested with reinforcement intact fail some distance away from the weld, whilst those tested with reinforcement removed usually fail in the weld metal. In both instances the tensile efficiency is of the order of 95%

and, in particular, the proof stress of the joint is higher than that of any other as-welded aluminium alloy.

Characteristics of welding processes

Fusion welding processes can affect the performance of a welded joint according to their proneness to permit defects, to their heat input, and to the weld bead profile that they tend to give.

Oxy-acetylene welding is rarely, if ever, used nowadays for structural applications in aluminium because welding speeds are too slow and weld quality is inadequate in the most suitable structural alloys. However, the process still finds application in sheet metal work in pure aluminium and NS.3, where the weld beads are characterized by the smooth way in which they blend into the surface of the parent material and, frequently, by the absence of reinforcement.

Metal-arc welding with flux-coated electrodes also finds little application for structural work on account of inadequate weld soundness and corrosion hazards from the remains of welding flux. However, several investigators have tested gas and metal-arc welded joints in fatigue, and the results give an interesting comparison with other welding methods. For some materials, results from gas and metal-arc welds provide the only available information.

Most structural welding of aluminium is carried out by the inert-gas tungsten-arc (Tig) and inert-gas metal-arc (Mig) processes. The former, which has the advantage of allowing independent control of heat input and filler addition, gives smooth, slightly convex weld beads and allows crater filling at the ends of runs. Relative to the Mig process, it is slow and will produce wider heat-affected zones in work-hardened and heat-treated materials. Because of its high speed and its ability to be used in all positions, the Mig process is usually favoured for work on aluminium structures. The weld bead produced by this process is generally rougher and, without careful control, is more convex than that laid by the Tig method. Craters at the ends of runs are also more difficult to eradicate.

Published work on fatigue of welds

The earliest published work on the fatigue behaviour of aluminium welds is that by Hartmann, Holt and Zamboky.[1] Specimens in $\frac{3}{8}$ in. thick 61S* covering a wide range of butt, strapped-butt, lap, and fillet joints made by the manual metal-arc process were tested in pulsating tension. Later in 1947, Templin and Holt[3] gave details of tests carried out on the Al–Mn alloy 3S. For $\frac{1}{8}$ in. and $\frac{3}{8}$ in. thick material, testing was by pulsating tension; for $\frac{1}{16}$ in. material reversed bending was employed. The specimens contained transverse butt welds and were tested with and without reinforcement.

The first information on the performance of Tig welds was given in 1951 by Oberg and Ward,[4] who carried out reversed bend tests on cantilever specimens with transverse butt joints. As-welded and post-weld heat-treated 14S and 75S were tested. In 1953 Muller-Busse[5] published the results of tests on an Al–Cu–Mg alloy similar to H.15. Butt joints made by the oxy-acetylene and metal-arc processes were subjected to alternating stress axial load tests and to alternating bending tests. Tungsten-arc welds in this material were also tested in reversed bending. An Al–3% Mg alloy similar to N.5, and an Al–Mg–Si alloy similar to H.30, butt jointed by gas and Tig welding were also tested in alternating bending. In 1954, Hartmann, Holt and Eaton[6] reported the results of pulsating tension tests on butt, lap, and fillet joints in $\frac{3}{8}$ in. thick 61S, 54S, Alclad 14S, and 3S. Welds were made by the metal-arc, carbon-arc and Tig processes. Their paper is of special interest because, for the 61S material, a welded butt joint is compared with a double-strap riveted butt joint.

Some results of reversed bending tests on an Al–Zn–Mg alloy were reported by Muller-Busse in 1956.[7] Butt joints were made by the gas and Tig methods and the results are compared with similar joints in an Al–5% Mg alloy in hard temper.

In a paper presented in 1955, Oldridge[8] briefly described the results of pulsating tension fatigue tests on Mig butt-welded joints in $\frac{1}{4}$ in. thick NS.6 and $\frac{1}{2}$ in. thick NP.5/6 alloys. These were compared with a riveted lap joint in $\frac{5}{16}$ in. thick N.6. Details of the tests on welded specimens are given by Oldridge and Houghton[9] in 1957. A publication on inert-gas tungsten-arc welding by Aluminium-Industrie-A.G., Zurich in 1958[10] gives repeated bending fatigue strengths for an endurance of 10^7 cycles for pure aluminium and a wide range of alloys, for specimens containing transverse gas welds. Newman[11] has recently reported on pulsating tension fatigue tests on $\frac{1}{4}$ in. thick HE.30 and NP.5/6 alloys containing transverse butt welds made by both the inert-gas processes. The results are discussed in relation to those given by the other investigators.[6, 9] Develay[12] has tested alloys similar to N.5 and N.6 by applying reversed bending to butt, lap, and fillet welded assemblies. These results are of particular interest, for they are the first from tests in which alternating stress has been superimposed on a mean stress. Very recently, Wood[13] has reported the results of reversed bending tests on Mig welds in $\frac{1}{4}$ in. thick NP.5/6. These tests included a brief examination of the effects produced by various post-welding treatments.

The only known paper describing fatigue tests on a welded structural detail in aluminium alloy is that published in 1951 by Boccon-Gibod.[14]

Factors Affecting Fatigue Strength of Welded Joints

Whilst much of the published work assesses the fatigue performance of welded aluminium in relation to the welding process employed, it is of value to consider this also in terms of the various metallurgical, geometrical, and physical factors which may operate. In this way important design considerations and aspects of welding technique which require precise control can be emphasized. These factors may be enumerated as follows:

(1) **Metallurgical**
- (*a*) Parent metal composition and condition
- (*b*) Weld metal composition
- (*c*) Heat-affected zone

(2) **Geometrical**
- (*a*) General joint configuration
- (*b*) Weld bead profile
- (*c*) Internal defects

* For details of this and other American alloys see Table II.

Table II

Mechanical properties of various American aluminium alloys

Alloy Group	*U.S. Designation*	*Alloy Type*	*Similar BS/GE Spec. For Sheet or Plate*	*Temper Designation*	*Typical Tensile Properties 0·2% Proof Stress tons/sq.in.*	*Tensile Strength, tons/sq.in.*	*Fatigue Strength,* tons/sq.in.*
Non-heat-treatable	2S now 1100	Pure Aluminium	S1C	O—Annealed	2·24	5·8	2·3
	3S now 3003	Aluminium–1¼% Manganese	NS.3	O—Annealed	2·48	6·3	3·2
			—	F—As manufactured	7·75	10·2	—
	4S now 3004	Aluminium–Manganese Magnesium	—	O—Annealed	4·45	11·6	6·4
	50S now 5050	Aluminium–1½% Magnesium	—	O—Annealed	3·58	9·8	5·4
	52S now 5052	Aluminum–2½% Magnesium	NS.4	O—Annealed	5·8	12·6	7·6
	A54S now 5154	Aluminium–3½% Magnesium	NS.5	O—Annealed	7·6	15·6	7·6
	56S now 5056	Aluminium–5% Magnesium	NS.6	O—Annealed	9·8	18·7	9·0
Heat-treatable	61S now 6061	Aluminium–Magnesium–Silicon	HS.20	T.4—Naturally aged (W)	9·35	15·6	6·4
				T.6—Artificially aged (WP)	17·85	20·0	6·4
	14S now 2014	Aluminium–Copper Magnesium–Silicon	HS.15	T.4—Naturally aged (W)	18·8	27·6	9·0
				T.6—Artificially aged (WP)	26·8	31·0	8·05
	24S now 2024	Aluminium–Copper–Magnesium–Silicon	—	T.4—Naturally aged (W)	21·4	30·2	8·05
	75S now 7075	Aluminium–Zinc–Magnesium	DTD.683A	T.6—Artificially aged (WP)	32·1	37·1	9·4

* Based on flexure tests at 500×10^6 cycles

(3) **Physical**
(*a*) Method of stressing
(*b*) Mean stress
(*c*) Residual or internal stress
} These two factors are often regarded as being analogous in their effects on fatigue performance.

In assessing the relative importance of these factors the service life requirement must be borne in mind.

Metallurgical factors

Parent metal composition and condition

Figure 1 shows the relationship between the typical tensile strength and the fatigue strength of plain specimens for a life of 500×10^6 cycles, when tested in rotating bending,[15] for a range of American materials most of which have close equivalents in Britain (Table II). In the annealed condition, both heat-treatable and non-heat-treatable alloys have a fatigue strength approximating to one half of the tensile strength, and of the same order as the proof stress. Hardening by cold working produces an increase in fatigue strength, not large in comparison with the increase in tensile strength (Fig. 1), and relatively small compared with the elevation of proof stress (Table III). Whilst solution heat-treatment and natural ageing (*W* condition), applied to materials such as 61S, produces an increase in fatigue strength of 50%, it is not comensurate with the increase in tensile properties, and a further increase in proof stress and tensile strength brought about by artificial ageing (*WP* condition) is not accompanied by any increase in fatigue strength.[15]

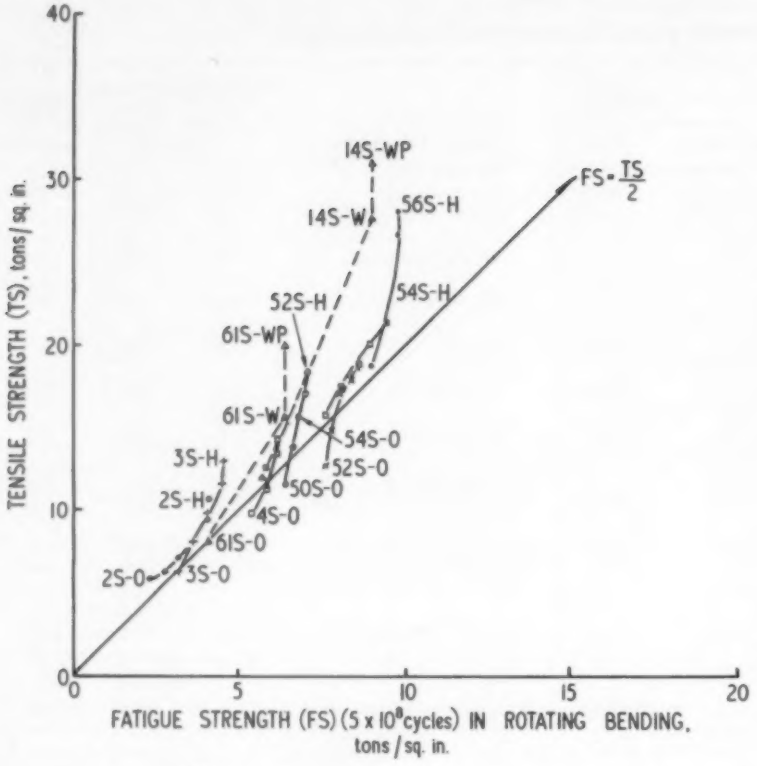
Table III

Effect of cold working on static and fatigue properties of plain specimens of certain non-heat-treatable materials

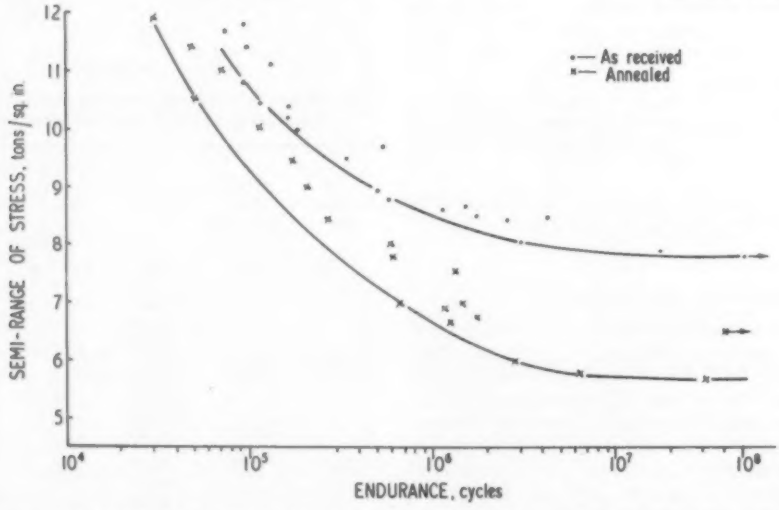
U.S. Designation	*BS/GE Sheet Equivalent*	*Temper*	*Tensile Properties 0·2% Proof Stress, tons/sq.in.*	*Tensile Strength, tons/sq.in.*	*Fatigue Strength* at 500×10^6 cycles*
2S	S1C	Soft	2·3	5·8	2·3
		¼ Hard	6·7	6·9	2·7
		½ Hard	7·6	7·8	3·1
		¾ Hard	8·9	8·9	3·8
		Hard	9·8	10·7	3·8
52S	NS4	Soft	5·8	12·6	7·6
		¼ Hard	12·5	14·8	7·8
		½ Hard	13·8	17·0	8·05
		¾ Hard	15·6	17·9	8·4
		Hard	16·5	18·7	8·6
54S	NS5	Soft	7·6	15·6	7·6
		¼ Hard	13·4	17·4	8·05
		½ Hard	14·7	18·7	8·6
		¾ Hard	16·1	20·0	9·0
		Hard	17·4	21·4	9·4

* Based on flexure tests

It might be expected that the fatigue strength quoted for annealed or 'as-manufactured' materials could be taken as a good indication of the fatigue strength of butt-welded joints free from defects and with the



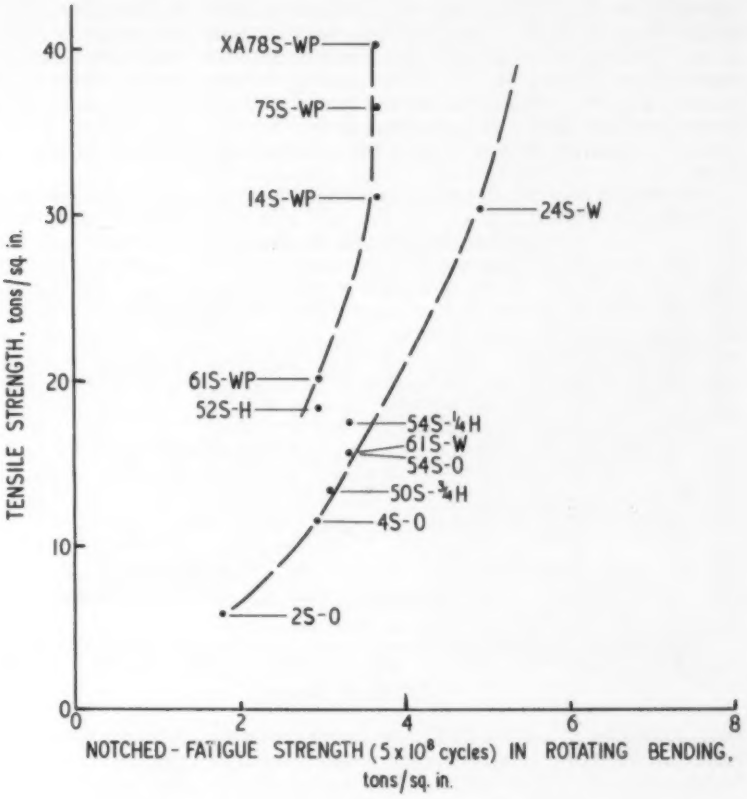
1—*Relationship between fatigue strength and tensile strength for various aluminium alloys*[15]



2—*Effect of annealing on flexural fatigue strength of ½ in. thick aluminium alloy NP.5/6 plate*[13]

reinforcement removed to obviate stress concentrations. However, particularly for Al–Mg alloys such as NP.5/6, which work-harden very rapidly, there is evidence that the fatigue strength under reversed loading conditions increases notably as a result of only slight plastic strain prior to testing; more severe plastic strain produces only a slight increase in fatigue strength. Figure 2[13] shows the effect of annealing 'as-manufactured' NP.5/6 plate, and indicates that published fatigue strengths for reversed loading of annealed or 'as-manufactured' material in the range ± 8 to ± 10 tons/sq.in. cannot represent the annealed condition alongside a weld where full softening will occur and for which a value of $\pm$ 6·5 tons/sq.in. is to be expected.

Figure 3 shows the rotating bending fatigue strength of severely notched specimens as a function of tensile strength,[15] again for lives of 500×10^6 cycles, from which it is evident that under long life conditions the fatigue strengths of the strongest heat-treatable materials are only slightly higher than those of the low-strength alloys, though significantly higher than



3—*Relationship between notched fatigue strength and tensile strength for certain aluminium alloys*[15]

Table IV

Static and fatigue strength of various aluminium alloys, welded and unwelded (A.I.A.G.—Zurich)

		Parent Material				*Oxy-acetylene Welded Butt Joints*	
Type		*0·2% Proof Stress, tons/sq.in.*	*Tensile Strength, tons/sq.in.*	*Fatigue Strength at 10^7 cycles tons/sq.in.*	*Filler Alloy*	*Tensile Strength, tons/sq.in.*	*Fatigue Strength at 10^7 cycles, tons/sq.in.*
S1B	O	1·2– 3·2	4·4– 6·3	2·5–3·2	Al	4·4– 6·3	1·9–2·5
	½H	5·1– 8·2	5·7– 9·5	3·2–3·8			
	H	7·6–10·2	8·2–11·4	3·8–4·4			
NS.3	O	2·5– 4·4	6·3– 7·6	3·5–4·1	Al	6·3– 8·2	2·9–3·8
	½H	6·3–10·7	8·2–11·4	3·8–4·4			
	H	10·7–15·9	12·1–15·9	4·1–4·7			
Peraluman 15 (1·5% Mg)		3·2– 5·1	8·9–10·7	4·1–4·7	Peraluman 30	8·9–10·7	3·5–4·1
	½H	9·5–12·7	10·7–13·3	4·4			
	H	12·7–15·2	13·3–15·9	4·4–5·1			
Peraluman 30 (3% Mg)	O	5·1– 8·9	13·3–15·2	5·7–6·3	Peraluman 30	13·3–15·2	4·4–5·7
	½H	12·7–15·9	14·6–17·8	6·3			
	H	15·9–20·3	17·8–22·2	6·3–7·6			
Peraluman 50 (5% Mg)	O	7·6–11·4	16·5–20·3	5·7–7·0	Peraluman 50	17·2–19·0	5·1–6·3
	H	18·4–22·2	21·6–25·4	6·3–7·6			
Anticorodal (HS.30)	W	8·9–13·3	15·2–19·0	5·4–6·0	Aluminium–4% Silicon	9·5–12·7	4·4–5·7
	WP	17·2–24·2	20·3–26·7				
Avional-23 (HS.15)	WP	17·8–21·6	27·3–31·8	7·0–8·2	Avional	17·2–20·3	
Re-heat treated						24·1–28·0	5·7–7·6
Unidal (Al/Zn/Mg)		8·9–12·7	15·9–20·3	5·4–6·0	Al–4% Si	12·7–16·5	
					Peraluman 30	12·7–15·2	4·4–5·7
					Peraluman 50	14·6–17·8	

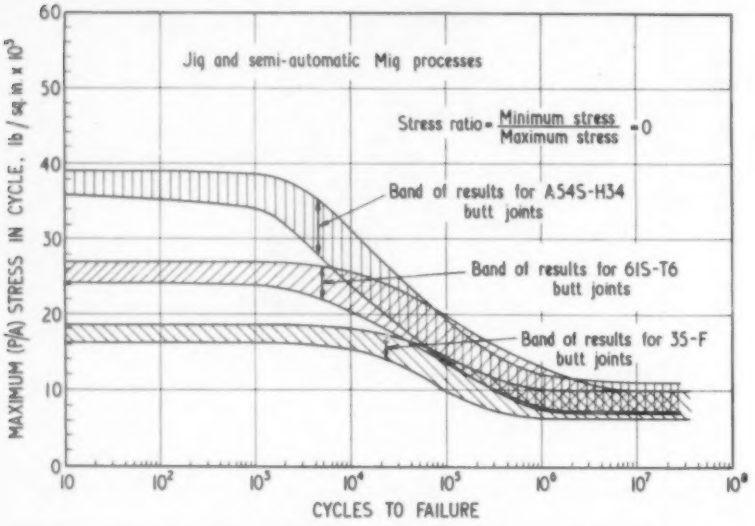
that of pure aluminium. From this it might be concluded that, for butt joints with the reinforcement intact, the long-life fatigue strength would tend to be only slightly affected by the static strength of the parent alloy. This is borne out by the results of Hartmann, Holt and Eaton[6] as reproduced in Fig. 4.

It will be observed from Fig. 1 that the long-life fatigue strength of heat-treatable alloys under reversed loading is virtually the same for the naturally aged as for the artificially aged condition. This can be taken to indicate that, under such conditions, welded joints in naturally aged material will have the same strength as those in artificially aged material. It might be expected that re-heat-treatment after welding would not effect any improvement in fatigue strength and Newman[16] has confirmed that for HE.30 this is so.

It is difficult to give typical fatigue strengths even for simple butt joints in a range of materials, because few investigators have used either the same welding process and technique or tested their specimens under the same stress system. The values quoted by A.I.A.G. (Table IV) for oxy-acetylene butt welds tested under reversed bending, with the reinforcement removed, show a definite increase in fatigue strength with increase in tensile strength for the non-heat-treatable materials, and are at variance with the results of Hartmann, Holt and Eaton, shown in Fig. 4, possibly because the latter appear to have included results from specimens with and without reinforcement. However, both sources agree that, for lives of 10^7 cycles, there is little difference between the fatigue strength of the non-heat-treatable Al–3% Mg alloy and the heat-treatable Al–Mg–Si alloys. The results of Newman[11] confirm that similar butt joints in NP.5/6 and HE.30–*WP* have similar fatigue strengths.

The S/N curves for reversed bending obtained by Muller-Busse on an alloy of the Unidal type (4·7% Zn, 1·2% Mg, 0·3% Mn)[7] compare generally with those which he shows for the Al–3% Mg alloy and two heat-treatable alloys similar to H.30 and H.15 respectively.[5] From the viewpoint of fatigue, the particular advantage of the Unidal type of alloy would therefore appear to be its ability to withstand useful ranges of alternating stress at higher mean stresses than are possible with other alloys. The fatigue behaviour of this class of material warrants further study.

In general it would appear that reasonably good, simple butt joints in non-heat-treatable materials welded by the inert-gas shielded-arc processes, and left with the reinforcement intact, will have an alternating stress fatigue strength for lives of 10^7 cycles ranging, with increase in static strength, from not less than one third of the tensile strength of the annealed parent metal, for pure aluminium, to one fifth for NP.5/6.



4—Comparison of direct-stress fatigue test results for arc-welded ⅜ in. thick aluminium alloy plate[6]

Weld metal composition

Almost always where the position of fatigue failure is reported, it is found that for sound, as-welded butt, lap, and fillet welds lying at right angles to the loading direction, failure occurs along the edge of the weld. Thus it is clear that unless the weld metal is severely defective it is not an important factor in the fatigue behaviour of joints, where stress concentrations or secondary stressing exist. Where reinforcement is removed from butts in non-heat-treatable materials, failure usually takes place in the weld metal, when parent metal filler or electrode wire is employed; it is concluded that the fatigue strength of weld metal free from gross defects is slightly lower than that of the annealed parent material. There seems to have been no systematic investigation of the fatigue strength of joints in a given material welded with different filler alloys, but from preliminary tests Walser[17] suggests that butt joints in an HE.30 type alloy, made with Al–5% Si and Al–5% Mg alloy filler, have substantially the same fatigue strength in repeated bending. In their work on simple butts in 3S, Templin and Holt[3] tested ⅜ in. thick plate carbon-arc welded with pure aluminium filler and metal-arc welded with Al–5% Si alloy filler, which should give under- and over-matching weld metal respectively. Since the reinforcement was removed in both instances, differences due to the welding method were partially removed, and the fact that the fatigue behaviours under pulsating tension were almost identical

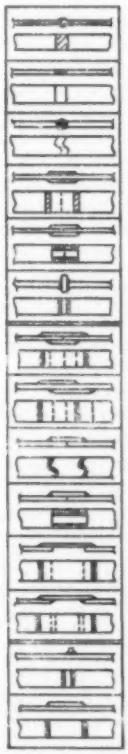
can be taken to indicate that such variations in weld metal composition have little effect. However, it would be of value to have further tests on joints where the weld metal over-matches the parent material in strength, as in the case of NP.4 welded with Al–5% Mg alloy filler metal.

Heat-affected zones

In their tests on butt joints in 61S with the reinforcement intact Hartmann, Holt and Eaton[6] observed that a few specimens with very smooth weld beads failed in the heat-affected zone. Newman's results[11] on HE.30 confirm that when the reinforcement is intact failure usually occurs from the edge of the weld bead; in only one case did the main fracture occur in the parent metal away from the weld. Even then cracks had started at the edge of the weld bead, and by comparison with other results there appeared to be no reduction of life for this specimen. Hartmann, Holt and Eaton found that in specimens of 61S where the weld reinforcement was removed, failure generally occurred in the heat-affected zone, with about 20% of the failures occurring through the weld metal. However, they are not specific in their reference to the heat-affected zone and their illustrations make it difficult to determine whether the fractures were in the over-heated or over-aged region. Figure 1 shows that for 61S alloy the fatigue strength of annealed material is significantly lower than that of metal solution treated and naturally aged (*W* condition). Thus, if the metal in the over-aged region was almost fully annealed, *e.g.*, as a result of the use of a particularly low welding speed, the fatigue strength at that point would be of the same order as that of the metal at the edge of the weld bead, which is almost in the *W* condition, but subjected to the stress concentration arising from the presence of the reinforcement. Thus it might be predicted that, when joints are tested with the reinforcement intact, occasional heat-affected-zone failures may be experienced and that, when sound butts are tested with the reinforcement removed, a higher proportion of heat-affected-zone failures would be expected because of the removal of the stress concentration at the edge of the weld bead, where the

Table V

Summary of results of tests by Hartmann, on 61S-T6 material

	Joint Type	*Design Configuration*	*Tensile Strength, tons/sq.in.*	*Joint Efficiency*	*Fatigue Strength,* tons/sq.in.*	*Strength Reduction factor*
	–	Monoblock (parent plate)	20·6	1·00	6·2	1·00
Symmetrical	2		11·9	0·58	2·8	0·45
	1		10·4	0·50	3·4	0·55
	9		10·8	0·52	2·5	0·40
	5		11·3	0·55	2·0	0·32
	15		5·7	0·28	1·2	0·19
	10		10·0	0·48	2·2	0·35
Unsymmetrical	6		10·1	0·49	1·2	0·19
	7		8·5	0·41	1·2	0·19
	8		4·8	0·23	0·7	0·11
	13		3·9	0·19	<0·35	<0·06
	3		4·4	0·21	0·7	0·11
	4		9·4	0·46	0·7	0·11
Attachments	11		10·2	0·49	3·5	0·57
	12		11·3	0·57	2·9	0·47

* Axial load test (R = 0) results from 10^7 cycle endurance

metal would be in the solution treated and naturally aged (*W*) condition.

For the non-heat-treatable alloys, the zone of annealed and partially annealed material on each side of the weld metal determines the maximum possible joint strength, for the fatigue strength here is usually significantly lower than that of the 'as-manufactured' material. It does, however, remain slightly stronger in fatigue than the weld metal, for butts in non-heat-treatable material tested with the reinforcement removed tend to fail either in or at the edge of the weld metal.[13]

Geometrical factors

General joint configuration

The fatigue strength of a welded connection is strongly influenced by the joint configuration.

Hartman, Holt and Zamboky[1] have tested a wide variety of joint configurations in $\frac{3}{8}$ in. thick 61S-T.6 aluminium alloy welded by the manual metal-arc process. Under pulsating tension loading, a broad distinction can be drawn between joints that offer a symmetrical load path and give a better fatigue strength than unsymmetrical joints in which secondary bending stresses become effective. Table V has been compiled from the results reported by Hartman *et al* and shows this distinction clearly. Symmetrical as-welded joints can be arranged in order of descending fatigue strength as follows: a transverse butt (Type 1); a cruciform connection with transverse fillet welds (Type 10); a double-strapped butt with equal-size cover plates attached by transverse fillet welds (Type 5); and a double-strapped butt with equal-size cover plates attached by longitudinal fillet welds (Type 15). The ratio of fatigue strength between the best and the worst is 2·33:1. The ratio between the best symmetrical configuration and the worst unsymmetrical arrangement is 8·0:1.

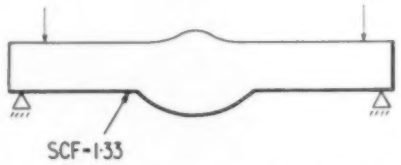
A similar general classification is found for as-welded steel connections. Whitman[18] quotes typical figures for the fatigue strength of butt and fillet welds which give a ratio between the best and the worst of 2·40:1. Weck[19] has suggested that aluminium alloys should be expected to be more sensitive to the effects of welding than steel. Table VI compares the strength reduction factors (fatigue strength of joint divided by fatigue strength of parent material) for butt welds in steel and aluminium. This indicates that the aluminium alloys are likely to be more sensitive to the combined effects of welding, but the actual strength reduction factor appears to be less influenced by the method of stressing in aluminium alloys than in steel.

Develay[12] has made reversed bend fatigue tests, using cantilever specimens incorporating various joint configurations. A uniform mean stress was applied for all the tests, so that the results are not directly comparable with any others. However, by comparing the stress ranges obtained at 10^8 cycles it is found that the ratio of the best as-welded joint (transverse butt) to the worst as-welded joint (transverse single fillet lap) is 7:1. The fatigue strength of the latter type of joint is greatly influenced by the arrangement of the joint in relation to the applied load. The ratio of fatigue strength of a joint in which failure occurs at the toe of the fillet and a joint in which failure occurs through the fillet (presumably initiated at the root) can be as high as 4·5:1.

Develay also shows that the fatigue strength of a single-pass butt-welded joint is lower when the maximum tensile stress in the cycle is applied to the underbead than when the upper surface is the more highly stressed. This observation is true also when the reinforcement is removed. Furthermore, there is scarcely any increase in fatigue strength by the removal of the reinforcement when the underbead side carries the maximum tensile stress.

Weld bead profile

There is no doubt that the change of section occurring at the junction of a weld bead and the surface of



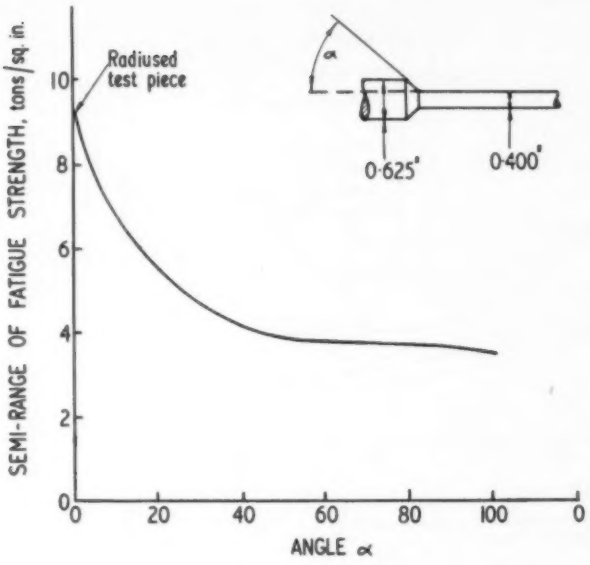
5—Outline of photoelastic specimen used to determine stress concentration factor (SCF) in butt weld profile (reproduced from ref. 20)

Table VI

Comparison of strength reduction factors of as-welded butt joints in steel and aluminium

Test Method	*Material*	*Weld Method*	*Fatigue Strength tons/sq.in. Before Welding*	*Fatigue Strength tons/sq.in. As-welded*	K_f †	*Ref.*
Axial Loading	$\frac{1}{2}$ in. BS.15 steel, as-received	Manual metal-arc. From both sides	16·0	11·5	0·72	Newman & Gurney
	$1\frac{1}{4}$ in BS.15 steel, stress relieved	Submerged-arc. From both sides	13·0	10·0	0·77	
	$\frac{1}{4}$ in. N.P.5/6	Tig. From both sides	12·0	5·7–7·5	0·42–0·62	Newman
		Mig. From both sides	12·0	3·5–5·5	0·29–0·46	
	$\frac{1}{4}$ in. HE.30–WP	Tig. From both sides	10·0	3·5–6·0	0·35–0·60	Newman
		Mig. From both sides	10·0	5·5–7·0	0·55–0·70	
Reversed Bend	$\frac{1}{2}$ in. Boiler Plate	Manual metal-arc. From both sides	15·2	8·1	0·53	Lea&Parker
	Rail steel (C–Si–Mn)	Electric-arc	24·0	12·7	0·53	Wyss
		Oxy-acetylene	24·0	11·4	0·48	
	$\frac{1}{4}$ in. NP.5/6	Mig. From both sides	7·9	3·75	0·475	Wood
	2 mm Pantal*	Tig. From both sides	7·3	3·8	0·52	Muller-Busse

* An Al–Mg–Si alloy equivalent to BS.H.10/H.30 † Strength Reduction Factor



6—*Fatigue strength of NE.6*M, *with stress concentration simulating as-welded profile*

the parent material constitutes a serious stress concentration. Koziarski[20] and others have illustrated this photo-elastically. Koziarski quoted a true stress concentration factor of 1·33 at the face side of the weld profile shown in Fig. 5 under a constant bending moment, which compares with 1·52 found by Wood[13] for Mig butts in NP.5/6 tested under reversed bending.

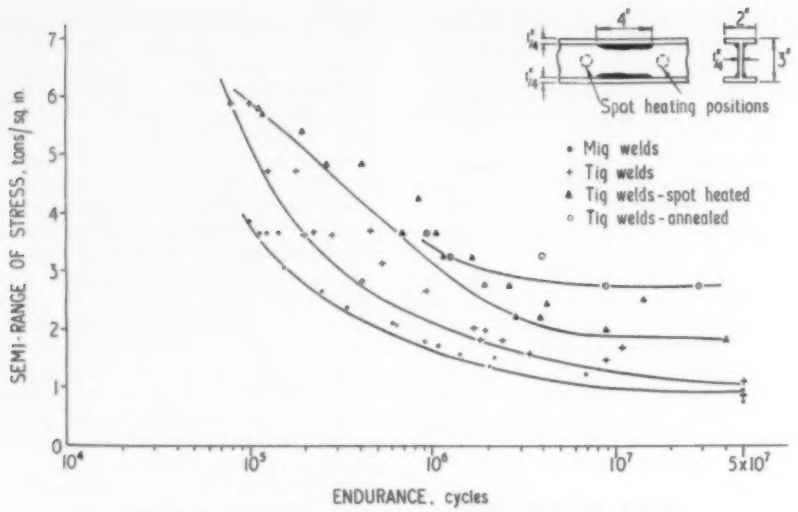
In general, fatigue failures in specimens of sound, simple butt joints tested with the reinforcement intact, or of lap or fillet joints, occur at the junction of the weld bead and the parent metal[6, 11, 12] though a few specimens of butts in heat-treatable alloys failed in the overheated zone in cases where the reinforcement was slight and the bead smooth.[6] Failure from the weld edge tends to occur from the edge of the underbead in single-pass joints and from the edge of the more convex bead in joints made from both sides.[11]

Attempts to show a correlation between weld bead shape and fatigue strength have been made by Newman and Gurney on butt-welded BS.15 steel specimens[21] and by Wood[13] on butt-welded NP.5/6 aluminium alloy. In both cases the weld bead shape has been assessed in terms of the angle between a tangent to the edge of the bead and the parent plate surface. The resulting plots show very wide scatter but there is some indication that, as the angle increases, the fatigue strength decreases. In recent tests on rotating cantilever specimens made from NE.6-*M* material, in which a change in diameter through various intermediate profiles was incorporated, the present authors have obtained a relationship between the transition angle and the 10^7 cycle fatigue strength of the form shown in Fig. 6. Whilst this type of test cannot be claimed to simulate fully the conditions existing in a welded sample, it is interesting to note that the strength reduction factor due to the angle being 24° is 0·55 compared with a value of 0·66 obtained by comparing the 10^7 cycle fatigue strength of annealed parent plate with as-welded butt-jointed specimens, in which the average bead edge angle associated with the fatigue failure was also 24°.

Muller-Busse has tested butt-welded joints in Al–Mg, Al–Cu–Mg, Al–Mg–Si and Al–Zn–Mg alloys by alternating axial loading or by reversed bending and shows in every case that joints made by gas welding are superior to arc-welded joints, whether these be made by the metal-arc or Tig processes. It is suggested by the author that the difference is primarily due to the flat bead obtained by gas welding, which causes less stress concentration at the bead edge than the high, steep sided bead produced by the arc-welding processes. It is interesting to note that the most abrupt change in section shown in ref. 5 is due to metal-arc welding and, for the Al–Cu–Mg alloy, produces the lowest fatigue strength at 10^7 cycles endurance. The bead edge profiles and fatigue strengths due to Tig welding fall between those obtained by the metal-arc and gas welding processes.

Removal of the bead reinforcement, and hence the stress concentration, from butt welds might be expected to improve the fatigue performance, and in general this is found to be true, although there are wide differences between the quantitative improvements reported by different investigators. Hartmann, Holt and Zamboky in their work on $\frac{3}{8}$ in. thick 61S obtained an increase from 2·8 to 3·4 tons/sq.in. in pulsating tension fatigue strength at 10^7 cycles, on removing the reinforcement from manual metal-arc welded transverse butt joints. Newman,[11] in a similar type of test on Mig-welded $\frac{1}{4}$ in. thick HE.30-*WP* obtained virtually no increase in fatigue strength on removing the reinforcement but attributes this to the presence of fine porosity on the dressed surfaces of the weld. Templin and Holt[3] found that the pulsating tension fatigue strength between 10^5 and 10^7 cycles of carbon-arc and metal-arc welded simple butts in 3S with reinforcement removed was from 2·2 to 2·7 times that of butts with the reinforcement intact; but it must be noted that the groups of specimens compared differed in thickness in the ratio of 3:1. Oldridge and Houghton[9] report increases in fatigue strength at 10^7 cycles from 4·8 to 5·5 tons/sq.in. for $\frac{1}{4}$ in thick Mig-welded NS.6-$\frac{1}{4}$H, and from 4·5 to 6·1 tons/sq.in. for $\frac{1}{2}$ in. thick Mig-welded NP.5/6, as a result of removing the weld reinforcement. From reversed bend tests on $\frac{1}{4}$ in. thick Mig-welded NP.5/6 Wood[13] reports an increase from 3·75 to 5·5 tons/sq.in. in the 10^7 cycle fatigue strength of sound welds, as a result of the removal of reinforcement, but notes that no improvement is obtained when the weld deposit shows only slight porosity.

A change of section is inherent in any fillet welded connection. Thus the stress concentration at a fillet weld cannot be eliminated, although it can be modified by machining the fillet to give a smooth junction with the parent metal. This aspect of the fatigue behaviour of fillet welds does not appear to have been investigated for aluminium alloys, but it is known that some improvement in the fatigue strength of steel fillet welds may be obtained by using unequal leg lengths and by machining the fillet. The success of these modifications must depend partly on the loading conditions, since it is clear that neither will alter the stress concentration at the weld root. For a loading condition which



7—Effect of welding process and post-weld treatment of fillet welds on fatigue strength of NE.6M I beams

normally causes failure from the weld toe it has been observed that modification of the fillet profile does not affect the position of failure. In repeated flexure tests on long I beams, containing four fillet beads between the flanges and the web at mid-span, and tested at resonant frequency, the present authors have found that beads laid by the Tig process give fatigue strengths consistently higher than beads laid by the Mig process (Fig. 7). Failures were invariably at the stops or starts of the beads, and the results are taken to indicate that the stress concentrations at the ends of Tig fillet welds are a little less severe than those at the ends of corresponding Mig welds.

Presence of internal defects

Although some reports[11, 13] make passing reference to the deleterious effect of porosity that breaks the surface of the joint, no systematic survey of the effect of defects can be traced. It is hoped that the current B.W.R.A. investigation of the effect of defects on the static mechanical properties of aluminium welds will be extended to cover fatigue behaviour.

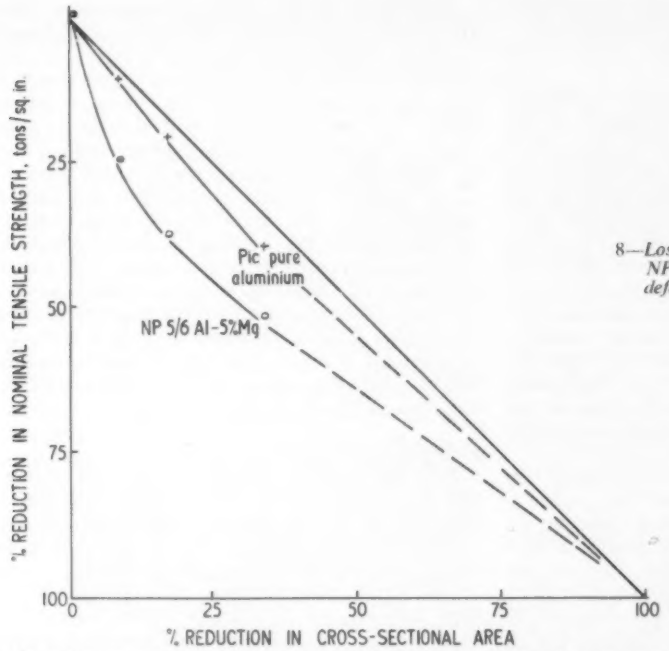
The present authors' views on the relative importance of defects are illustrated in Table VII. Admittedly they are based on experience of many static tests and a lesser number of fatigue tests, but they seem to be in general agreement with the contents of Newman's[21] review of literature on the effect of internal defects on the fatigue strength of welded steel joints. From his work on butt joints in NP.5/6, Wood[13] concludes that in comparison with the results obtained by Lea and Parker[23] on butt-welded mild steel, NP.5/6 is rather more notch-sensitive than mild steel; from their comparison of the fatigue behaviour of fillet welds in NP.5/6 and mild steel, the present authors have confirmed this conclusion. Thus it can be expected that the effects described by Newman will be proportionally a little more severe for NP.5/6, though possibly proportionally less severe for pure aluminium. It seems well established[13, 22] that when the reinforcement is

Table VII

Probable relative importance of defects

Surface Defects	*Internal Defects*	
(1) Important under axial and bending stresses (2) Of over-riding importance if weld metal is free from gross internal defects	(1) Sub-surface defects less important under bending than axial stresses (2) More important when surface defects are absent and *especially* when reinforcement is removed	
	As-welded Condition	*Reinforcement Removed*
Cracks normal to the direction of stressing Lack of penetration in welds made from one side Suck-back and undercut Underbead defect*	Cracks normal to the direction of stressing Lack of penetration in welds made from both sides Lack of fusion Cavities Distributed oxide inclusions Distributed porosity	Even small defects are likely to cause the fatigue strength to be within the scatter band for 'as-welded' joints
Obtuse reinforcement and overlap† Arc strikes, surface burning and heavy, adhering spatter‡		

* Depending on its severity, it may be eliminated by removal of underbead. Where fatigue is important, dye penetrant or other test should be applied after removal.
† Eliminated by removal of reinforcement.
‡ Eliminated by careful grinding.



8—Loss of static strength of pure aluminium and NP.5/6 alloy through synthetic, sharp planar defects, as a function of loss of area

left on butt joints, a higher level of internal defect can exist without adversely affecting the fatigue strength than when the reinforcement is removed. Also it has been noted[6, 13] that surface damage, such as arc-strikes, surface burning owing to poor earth contact in arc-welding, and coarse grinding (leaving grooves normal to the direction of the principal stress) can initiate fatigue failures.

The difficulty of ensuring that the removal of reinforcement from simple butt joints will improve fatigue strength can be appreciated qualitatively by reference to Homès' work on porosity in mild steel butt welds,[24] which shows that while the presence of 2% porosity produces a 26% decrease in fatigue strength, 4% porosity only produces a total decrease of 36%. That similar effects are likely in aluminium welds is suggested by the present authors' results from static tests on pure aluminium and NP.5/6 containing synthetic planar defects (Fig. 8), which shows that small defects have a disproportionately large weakening effect.

Physical factors

Method of stressing

In tests on notch-free polished aluminium alloy specimens the fatigue strength obtained by axial loading is usually somewhat lower than is obtained by reversed bending.[15] For specimens with a transverse butt weld, axial load results are significantly below reversed bend results in all the reported cases. From tests on gas-welded butt joints in 3S material with the reinforcement intact, Templin and Holt[3] have shown that fatigue strength at 10^7 cycles of 0·064 in. thick sheet tested by reversed bending to be 3·5 times as high as that for 0·125 in. thick sheet tested by pulsating tension loading. The comparison is complicated by the difference in thickness between the samples used for the two testing methods, which may have been responsible for differences in weld bead profile as well as the more obvious 'size effect'. The authors attribute most of the variation in fatigue behaviour to the fact that the two test methods expose in different degree the effects of welding defects.

Muller-Busse[5] reports results from tests on soft Al–Cu–Mg alloy butt-welded by the oxy-acetylene and manual metal-arc processes. Alternating axial-load tests on 4 mm thick sheet, as-received and as-welded by both processes, gave results consistently lower than those obtained by reversed-bend testing 2 mm thick sheet. Ratios of reversed bend to axial fatigue strengths at 10^7 cycles are 1·75, 2·36 and 2·0 for the as-received, oxy-acetylene welded, and manual metal-arc welded conditions, respectively. Again, these comparisons are complicated by thickness differences but the variations in fatigue strength are of such a magnitude that they cannot be wholly attributed to 'size effect'.

A significant difference in the general form of the S/N curves produced by Muller-Busse is also apparent. The break in the curves obtained under alternating axial load occurs at endurances below 10^6 cycles, whereas for reversed bending the break comes at endurances between 4×10^6 and 2×10^7 cycles.

The pulsating tension test results from Mig butt-welded ¼ in. thick NP.5/6 plate, obtained by Oldridge and Houghton[9] and by Newman,[11] and the reversed bend results obtained from the same material by Wood,[13] which give ranges of fatigue strength at 2×10^6 cycles of 4·6–5·0, 3·5–5·5 and 3·8–5·0 tons/sq.in. respectively, show no really significant trend towards higher fatigue strength under axial loading conditions.

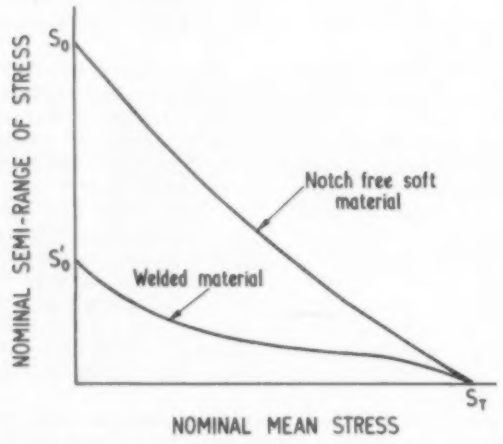
From the foregoing it may be concluded that the effect of the method of testing is real for butt-welded joints, but is strongly influenced by weld quality.

There are insufficient data on the behaviour of fillet welds to allow a similar assessment to be made.

Mean stress

The effects of mean stress on the fatigue performance of aluminium alloys have been demonstrated by Woodward, Gunn and Forest[25] and by Chadwick[26] by experiments on plain, notch-free specimens. In every case it has been shown that tensile mean stress causes a reduction in the range of alternating stress to produce failure at a given life. It is commonly believed that compressive mean stress permits increased alternating stress ranges, and this is shown to be correct, although the degree of improvement in range is less than might be expected in notch-free material. The improvement in the range withstood by materials such as HE.10-*WP* and HE.15-*WP* is maintained until the mean stress exceeds the proof stress of the material. A sharp drop in the alternating stress range then occurs.

No work has yet been reported which shows the effect of mean stress on welded aluminium alloys. Develay[12] used a constant mean bending stress for all his reversed bend tests, but the results presented do not indicate the effect of mean stress as such. Tests by the authors on $\frac{3}{16}$ in. thick butt-welded NP.5/6 show that the 10^7 cycle pulsating tension fatigue strength is reduced from 5·0 to 4·3 tons/sq.in. by the presence of a tensile mean stress of 3·0 tons/sq.in. Woodward *et al*[25] have shown on an R/M diagram that the constant endurance curves for a notched aluminium alloy are likely to be concave upwards for mean stresses below the nominal proof stress of the material. This shape is also a characteristic of materials having a low ratio of proof stress to tensile strength. Thus an as-welded connection, in which a stress concentration coincides with an annealed zone, will probably produce an R/M diagram of the general form shown in Fig. 9, when tested with a tensile mean stress. There is evidence from tests involving residual stress that compressive mean stress operating in the presence of a notch gives substantial improvement in fatigue strength. This is an aspect of the problem which calls for further investigation.



9—*Probable R/M diagram for welded aluminium alloy*

Chadwick[26] presents data for mean stress effects on HE.10-*WP* in a Walker diagram, and suggests a method of making allowances for various factors, including the reduction in fatigue strength due to joints and other stress concentrations, when estimating the relationship between mean and alternating stress. A 'factor of ignorance' is subsequently applied to cover the differences arising from the fact that service loading is unlikely to follow the idealized cycles used experimentally to obtain the R/M diagram. It is claimed that the Walker diagram is universally applicable but this is seen to be at variance with the results produced by Woodward *et al*., which show that constant endurance curves that are convex upwards are typical only of materials having a high ratio of proof stress to tensile strength. It is clear that there is still no single formula connecting fatigue strength and mean stress for all aluminium alloys.

Residual stress

Residual stress is inevitable in any welded assembly and is normally tensile in the immediate vicinity of the weld. In all but the smallest weldment the material surrounding the weld provides such restraint that the maximum level of residual stress is limited only by the 'proof' stress of the material. Thus it might be thought that residual tensile stresses would have the same deleterious effect on the tolerable range of alternating stress as that produced by a tensile mean stress arising from an externally applied force, and that post-welding stress relief would give some improvement in fatigue performance. In the few cases where investigators have applied such treatment to steel welds no significant improvement has been reported, and it has generally been concluded that residual stress is not an important factor in determining the fatigue strength of welds. Wood[13] has shown that for the aluminium alloy NP.5/6 full annealing of test plates containing a butt weld produces no change in the fatigue properties. If residual stresses transverse to butt unrestrained welds in thin material are generally lower than those existing in the direction of the weld, it would not be surprising that when specimens of such joints are tested in fatigue, with the direction of stressing transverse to the weld, the effect of stress relieving treatments is found to be negligible. Furthermore, the cutting of test joints into small specimens may also allow of some stress relief. Trufyakov[27] has shown that as the dimensions of a transverse butt-welded steel specimen are increased from 2·75 × 0·59 in. to 7·9 × 1·03 in., the flexural fatigue strength declines from 7·6 to 3·8 tons/sq.in. Increases in width or thickness beyond these dimensions have little further effect on the fatigue strength. By measuring the residual stresses, and from additional tests designed to show the effects of a change in residual stress, Trufyakov concludes that the drop in fatigue strength produced by the increased test piece dimensions is due almost entirely to residual tensile stress. It follows that a reliable demonstration of the effects of residual tension cannot be obtained by stress relieving small welded test pieces. In tests with fillet welds deposited on long, monolithic I beams, tested in reversed bending at resonant frequency, the present authors have obtained a 110% increase in the 10^7 cycle fatigue strength of Tig longitudinal fillet welds on NE.6-*M* material by annealing the entire

mid-span welded region of the specimen (Fig. 7). This improvement can only be attributed to relief of residual stress which, because of the configuration of the specimen, would be considerable.

Whilst attempts to show the effect of tensile residual stress have not always produced conclusive results, there are definite indications that compressive residual stress in the weld region can cause an increase in fatigue strength. Wood[13] reports an increase from 3·75 to 5·45 tons/sq.in. in the 10^7 cycle bending fatigue strength of butt welded $\frac{1}{4}$ in. thick NP.5/6 plate, as a result of quenching specimens in cold water from a temperature of 500°C. to introduce superficial compressive stresses. In 1956 Puchner[28] described a 'spot-heating' technique which was claimed to be responsible for substantial increases in the fatigue strength of certain welded steel specimens. This technique has been employed successfully by Gurney and Trepka[29] in pulsating tension tests on steel specimens with longitudinal butt and fillet attachments. Increases of up to 150% in fatigue strength are reported as a result of 'spot-heating' to produce residual compression in the longitudinal direction at each end of a weld. A similar result has been obtained by an indentation process arranged to leave the material immediately opposite the weld end in residual compression. There are indications that both these techniques are effective on the Al–5% Mg alloy NP.5/6. The present authors have obtained a 50% increase in the fatigue strength of NE.6-*M* material with longitudinal fillet welds by a 'spot-heating' technique (Fig. 7).

Stretching is a standard method of reducing residual stresses in sheet, plate, and extrusions and may also be used to correct distortion after welding. Forest[30] shows that a small percentage stretch can produce a very substantial reduction in residual stress. For welded non-heat-treatable alloys, the effect of stretching on fatigue strength is complicated by the work-hardening effect, particularly on the softened material in the heat-affected zone. In such cases an increase in fatigue strength is more likely to be the result of a change in the properties of the material in the softened zone than to a reduction in tensile residual stress. Wood[13] reports an increase from 3·75 to 5·4 tons/sq.in. in the 10^7 cycle fatigue strength of butt-welded specimens stretched in the longitudinal direction before being subjected to transverse reversed bend tests. No experimental results are reported to show the effects of stretching on welded heat-treatable alloys.

It is known that a deliberate overload applied to a notched specimen can produce a state of residual stress such that the fatigue performance is improved, but it is also possible that residual stresses may relax in time under cyclic loading.[31] If high-strain cyclic loading occurs in service, all residual stress may be removed within a few cycles. This has been demonstrated on welded specimens in steel and in aluminium alloy.[13,28] The S/N curves for specimens with and without compressive residual stress have shown a tendency to converge at a stress level approximately equal to the proof stress of the material. This effect is attributed to the relaxation of residual stress caused by straining the material beyond its elastic limit, so that a similar effect can be expected in specimens possessing residual tensile stress.

It is characteristic of as-welded connections that high residual tensile stress operates in regions where the stress concentration coincides with heat-affected material. It is conceivable that test or service loads, whilst insufficient to produce general high strain levels, may cause yielding at the edge of the weld bead. The affect on the residual stress may be beneficial to the fatigue performance but this depends upon subsequent service conditions.

The only conclusions which can be drawn at this stage are:

(*a*) Whilst there is very little proof, there is good reason to believe that relief of residual tensile stress should give improved fatigue performance
(*b*) Substantial relief of residual stress can occur locally if high strain conditions arise during test or at any time in the life of the structure
(*c*) For this reason, methods of improving fatigue strength, which depend upon compressive residual stress, can be permanently effective only where the load history of the welded assembly can be accurately foretold.

Comparison of Welded and Riveted Joints in Fatigue

Templin[15] has shown that the conclusions to be drawn from any comparison between welded and riveted joints are influenced by the method of estimating the applied stress. For welded connections it is customary to calculate the nominal stress applied to the joint on the basis of the parent-plate gross sectional area. For riveted joints the nominal applied stress may be calculated on the basis of gross area, *i.e.*, full parent plate section, or on net area, *i.e.* a cross section including a row of rivet holes. The gross area method is the most reasonable for comparative purposes, for with well-driven rivets completely filling the holes the increased nominal stress obtained from the net area method is effective only during those parts of a loading cycle involving tension. This effect is best accounted for by including it in the overall stress concentration factor due to the joint.

The comparisons given by Templin are derived from results obtained by Hartmann, Holt, and Eaton[6] from pulsating tension tests on a double-strapped riveted transverse butt joint in 61S-T.6 plate with rivets of the same composition. When the applied stress was estimated on gross area, the riveted joint was found to have the superior static strength, but fatigue test results for endurances below 5×10^6 cycles fell within the scatter band obtained from similar tests on arc-welded transverse butt joints. For endurances in excess of 5×10^6 cycles there are indications that the welded joint has a slightly higher fatigue strength than the riveted connection.

Comparison of the riveted joint results mentioned above with the results for a double-strapped butt joint with cover plates attached by transverse fillet welds obtained by Hartman, Holt and Zamboky (joint type 5 Table V), shows the riveted joint to be superior over the whole range of endurances up to 10^7 cycles.

Oldridge[8] has reported the results of tests on $\frac{5}{16}$ in. thick N6 specimens containing a riveted lap joint, made with three rows of aluminium alloy rivets. At an endurance of 10^7 cycles the pulsating tension fatigue strength was down to 1·6 tons/sq.in. Oldridge has not

reported results for welded joints of an exactly similar configuration, but a lap joint in $\frac{3}{8}$ in. thick 61S-T plate made with double transverse fillet welds (joint type 4, Table V) shows a 10^7 cycle fatigue strength in pulsating tension of only 0·67 tons/sq.in.

From these observations it is concluded that for a given type of joint the fatigue strength obtained by riveting the connection is likely to be higher than that obtained by welding. Welded construction permits the use of a simple butt joint, however, which has no equivalent riveted connection and which is capable of fatigue strengths at least equal to those of the best riveted joints.

Carefully designed welded structural connections can give fatigue strengths considerably better than those of an equivalent riveted connection. This has been demonstrated by Boccon-Gibod,[14] who tested several T-joint structural details made both by welding and riveting in N6 material. The results show the welded connections to be better than the best riveted joints for endurances of 10^8 cycles.

General Observations

Whilst there is sufficient evidence to show that the fatigue strength of sound, as-welded simple butt joints rises significantly with rise in static strength, at least for pure aluminium and the non-heat-treatable alloys, further information is needed in a number of cases before safe stress levels can be established.

In view of the importance of the angle at which the reinforcement of butt joints meets the parent material, methods of control are worthy of examination, for the only alternative means of improving fatigue behaviour is to ensure that the weld is virtually free from defects and then to dress it flush. Because of the shape of their reinforcement, oxy-acetylene welds have a definite advantage over those made by arc processes, and there is evidence that tungsten inert-gas welds are sometimes superior to those made by the inert-gas metal-arc process.

Recommendations covering the general design against fatigue failure of welded joints in steel[31] apply in a qualitative sense to aluminium: simple butt joints are preferred; as alternatives transverse shear joints are preferred to longitudinal shear joints. However, any 'factoring' of design stresses for simple butt joints to take account of poor joint configuration is likely to be a function of the stress concentration susceptibility of the material, and information on this point is needed for pure aluminium and at least two types of alloy.

For successful designs of high efficiency it is likely that methods of improving fatigue strength locally or generally by mechanical or thermal treatments after welding will have to be adopted. The study of such procedures is at an early stage and there are many aspects, such as the applicability of spot heating methods to heat-treatable materials and the parameters for spot heating and local working, that are obvious targets for further work.

Acknowledgments

The authors wish to thank the Directors of The British Aluminium Co. Ltd. for permission to publish this paper, and are indebted to the Admiralty for permission to refer to the work of Oldridge and Houghton.

REFERENCES

1. E. C. Hartmann, M. Holt and A. M. Zamboky: *Welding J.*, 1947, vol. 26, p. 129*s*.
2. "Argon-Arc Welding Aluminium—Metallurgical Considerations". British Welding Research Association, London 1957.
3. R. L. Templin and M. Holt: *Welding J.*, 1947, vol. 26, p. 705*s*.
4. T. T. Oberg and E. J. Ward: "Fatigue of Tungsten-Arc Butt-Welded Wrought Aluminium Alloys". A.A.F. Technical Report No. 6513. Wright Air Development Center, 1951.
5. A. Muller-Busse: *Aluminium*, 1953, vol. 29, p. 102. (Translation by A. D. A., Tech. Memo. No. 218.)
6. E. C. Hartmann, M. Holt and I. D. Eaton: *Welding J.*, 1954, vol. 33, p. 21*s*.
7. A. Muller-Busse: *Aluminium*, 1956, vol. 32, p. 333. (Translation by A.D.A., Tech. Memo. No. 333.)
8. C. P. Oldridge: "The Strength and Performance of Welded Joints and Their Influence in Design". Symposium on the Use and Welding of Aluminium in Shipbuilding. Institute of Welding, London, 1955.
9. C. P. Oldridge and A. W. Houghton: "The Fatigue Performance under Pulsating Tension of Welded Joints in $\frac{1}{4}$ in. and $\frac{1}{2}$ in. Al–Mg alloy". N.C.R.E. Report No. R.380, H.M.S.O., 1957.
10. "T.I.G. Welding". A.I.A.G. Publication, Zurich, 1958.
11. R. P. Newman: *Brit. Welding J.*, 1959, vol. 6, p. 324.
12. R. Develay: *Rev. Metallurgie*, 1959, vol. 56, p. 32.
13. J. L. Wood: "The Flexural Fatigue Strength of Butt-Welds in NP.5/6 Type Aluminium Alloy". *Brit. Welding J.*, 1960, May (in the press)
14. R. Boccon-Gibod: *Rev. Metallurgie*, 1951, vol. 48, p. 369.
15. R. L. Templin: "Fatigue of Aluminium". H. W. Gillet Memorial Lecture, A.S.T.M., 1954.
16. R. P. Newman: Private Communication.
17. H. Walser: Private Communication.
18. J. G. Whitman: "The Fatigue Properties of Welds". The Fatigue of Metals Symposium, University of Nottingham, September, 1955.
19. R. Weck: "The Fatigue Problem in Welded Construction". Proc. International Conf. Fatigue of Metals, Inst. Mech. Eng., London, 1956.
20. J. Koziarski: *Welding J.*, 1955, vol. 34, p. 446–458.
21. R. P. Newman and T. R. Gurney: *Brit. Welding J.*, 1959, vol. 6, p. 480.
22. R. P. Newman: *Brit. Welding J.*, 1959, vol. 6, p. 59.
23. F. C. Lea and C. F. Parker: "Second Report of the Welding Research Committee". Proc. Inst. Mech. Eng., 1936, Nov., p. 15–61.
24. G. A. Homès: *Arcos*, 1938, vol. 15, p. 1951.
25. A. R. Woodward, K. W. Gunn and G. Forrest: "The Effect of Mean Stress on the Fatigue of Aluminium Alloys". Proc. International Conf. Fatigue of Metals, Inst. Mech. Eng., London, 1956.
26. R. Chadwick: *Engineering*, 1954, vol. 178, No. 4615, p. 43.
27. V. I. Trufyakov: *Brit. Welding J.*, 1958, vol. 5, p. 491.
28. O. Puchner: *Schweisstech.* (Vienna), 1956, vol. 6 p. 109.
29. T. R. Gurney and L. N. Trepka: *Brit. Welding J.*, 1959 vol. 6, p. 465.
30. G. Forrest: *J. Roy. Aero. Soc.*, 1954, vol. 58, p. 261.
31. R. Weck: *Struct. Eng.*, 1954, vol. XXXII, April, pp. 115–129.
32. T. Wyss: *Zeit. Schweisstech.*, 1948, vol. 38, Nos.9–11.

SYMPOSIUM ON FATIGUE OF WELDED STRUCTURES

Future Research – Engineering Aspects

By E. M. Lewis, A.C.G.I.

The belief that present-day design practice in the field of civil engineering structures implies that fatigue cracking will occur in the planned life of structures leads to the consideration of two broad aspects of future research. One is concerned with the economic maintenance of existing structures, the other with the design of future welded structures. In regard to the maintenance aspect, a number of problems of inspection and repair, related particularly to fatigue cracking and based on actual service experience, have become apparent. In connection with design, the advantageous use of induced residual stresses can be foreseen, and further research into methods is necessary; the allocation of resources to full-scale environmental testing is regarded as an important step in securing informed design development.

Introduction

In dealing with the future there are three classical approaches. First, and probably the most respectable from a scientific viewpoint, is the one where the author traces the history of the subject and tentatively extrapolates a little to the future. The second is to examine what has happened in those industries which are leading, then to make the fairly safe assumption that cross-fertilization of ideas and information will result in other industries following; and finally there is probably the most hazardous approach, which is to catalogue the known problems and to offer some suggestions in regard to the way in which they may be tackled. At a symposium of this kind it is perhaps the last approach that is most helpful, and is the one which the author will attempt with some support by way of ideas and information from outside his particular field of civil engineering structures.

At the commencement it should perhaps be stated unequivocally that present-day design practice in the field of civil engineering structures implies that, within the planned working life of structures, fatigue cracking on a significant scale will occur. By way of illustration, Fig. 1 is a modified S/N curve showing the fatigue stress factors K_1 and K_2 from the current British Standard for Steel Girder Bridges (BS.153: 1958) plotted against the scatter band (shaded) of a large volume of published test data. The K_2 factor lies almost wholly within the band, and at large numbers of cycles approaching 10^7 it appears to become increasingly optimistic. The K_1 factor allows a margin of safety up to about 2×10^6 cycles but it seems likely that at figures approaching 10^7 cycles this too may imply that fatigue cracks are to be expected. The plot *A-B*, though derived from an isolated series of tests to determine the conditions under which a fatigue crack would initiate brittle fracture and which used an abnormally severe artificial notch,[1] is nevertheless included because it refers to fatigue cracks in mild steel up to $2\frac{1}{2}$ in. thick under high stress ranges, and supports *prima facie* some recent Russian work[2] showing that fatigue test results using relatively slender material may, when extrapolated to thick material, lead to optimistic estimates. Most of the test results in the shaded zones were for work on plates under $\frac{3}{4}$ in. thick. By way of practical illustration, four loading conditions, representing actual stress measurements and cycles counted with automatic counters in an open-hearth melting shop, are included, the numbers of cycles being based on a 50-year planned life assuming the present intensity of operation to be maintained.

Broadly, the field of future work falls into two categories. Firstly, that concerned with the economic maintenance of existing welded structures, and secondly that dealing with the design of future welded structures.

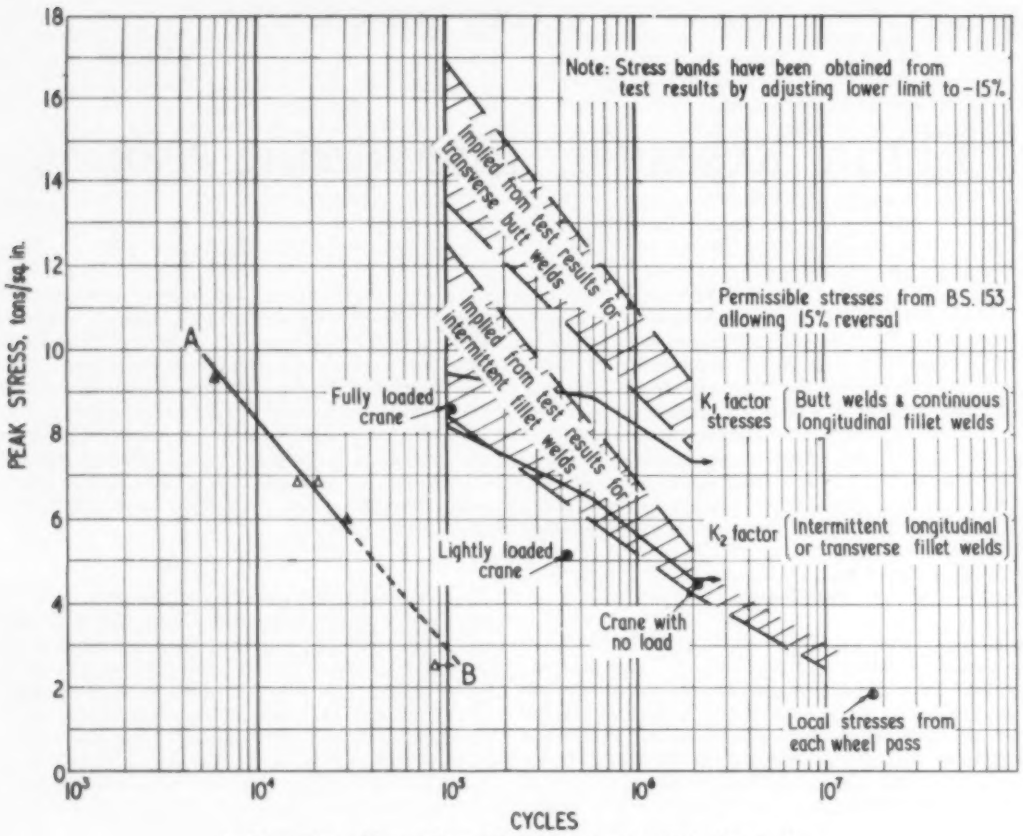
Maintenance

It is under this heading that perhaps fatigue problems are at the present time most urgent and therefore demanding of research. Most previous research in the author's knowledge, has been directed towards the better design of new structures. There appears to be but little systematic work into the problems of maintaining welded structures of various kinds at an adequate level of serviceability under working conditions which produce many fatigue cracks during their economic lifetime.

The term "maintenance" encompasses three main activities. Firstly, inspection to find the fatigue cracks when they occur; secondly, evaluation (that is, an assessment of their significance to determine whether repair is or is not necessary); and thirdly, repair itself.

Paper to be presented at a Symposium on Fatigue of Welded Structures, to be held at Cambridge University on 29th March–1st April, 1960.

Mr. Lewis is Director of Research with W. S. Atkins and Partners.



1—*Comparison of factors* K_1 *and* K_2 *in BS.153 with published test results*

Inspection

Maintenance engineers and research workers familiar with fatigue cracks in the laboratory are all aware that this form of cracking is among the most difficult to discern by visual inspection—particularly when the inspection is carried out with the structure quiescent. In general, fatigue cracks have to propagate for some inches before they can be readily detected by visual inspection techniques, which proved quite adequate for the detection of working rivets in earlier constructions performing the same duty.

Figure 2 is a histogram illustrating the way in which the number of fatigue cracks occurring per unit time (typically one inspection cycle) varies during the life of a structure subject to fatigue loading. The curve is idealized in that it assumes that there is one mode of failure and repeated failures, *i.e.*, repair failures, are ignored. There are two important points that stem from this classic distribution:

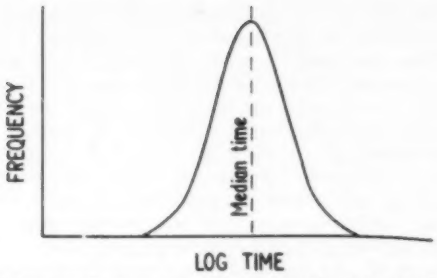
(*a*) If the inspection method is sensitive the engineer will become aware of a particular mode of fatigue cracking when only a small fraction, perhaps 2% or 3%, of possible failures have occurred, and these cracks will be small at the time

(*b*) For most civil engineering structures—bridges, gantry girders and the like—the calendar time interval between the detectable onset of fatigue and the median life at which fatigue cracking has occurred in half of the possible localities is unlikely to be less than several months and may be several years.

The implication of the first point is that if, on the discovery of one or two fatigue cracks, further examination of the structure reveals 20% or 30% cracking, this is a clear indication that the method of inspection is insufficiently sensitive. (Most readers will be familiar with apparent epidemics of fatigue cracking.) It is extremely rare for large numbers of cracks to appear at the same time, because of the wide difference in life which occurs with practical welded details between the shortest and longest life.

In regard to the second point, if the first fatigue cracks are revealed by routine inspection early on, then generally there will be ample time to design and plan an effective and economic repair scheme. Conversely, if the cracking is extreme before it comes to light the repairs tend to be rushed, ineffective, and costly.

In the structural field the presence of dirt and protective paint films often renders the application of penetrant and magnetic ink methods unsatisfactory and, to a lesser extent, interferes with ultrasonic techniques. There would appear to be an opening for research into a simple method for cleaning and paint-stripping local areas and quickly making good after inspection, but whatever advances may be made along these or other lines the dominant need is for a means of predetermining where fatigue cracks are most likely to occur, so that the zones subject to close



2—*Histogram of occurrence of fatigue cracks in identical specimens.*

scrutiny by any of these relatively costly techniques shall represent only a minute fraction of the total surface area of the structure.

Evaluation

After inspection has revealed a fatigue crack, the next step is to evaluate it, *i.e.*, to decide how much it weakens the structure, whether it will propagate, and if so when it will become dangerous.

Firstly, it may be considered that fatigue cracks are best left alone. Work by Frost[3] and others has proved that there is a definite category of non-propagating cracks. The criterion postulated by Frost is that $\sigma^3 l = 5{\cdot}5$ for mild steel in the case of alternating stress where σ is the nominal alternating stress and l is the crack length. He further postulates that it is the tensile half of the stress cycle that is damaging and hence arrives at the criterion that $\sigma^3 l = \frac{5{\cdot}5}{8}$ where the cycle is wholly tensile. Applying Frost's criterion to the wheel-pass loading case, shown in Fig. 1, which has a stress range of about 2 tons/sq.in., it would seem that a crack $\frac{5}{8}$ in. long would be quiescent. There is another category of cracks which may also possibly grow for a while and then stop. These are cracks which originate in fields of intense local locked-in tensile stress due to welding, and which may stop when they have once propagated into a compressive field. Much of the work on which Frost's hypotheses are based is on specimens differing widely from practical welding constructions, and which were invariably stress relieved. Therefore, some further confirmatory research would have to be undertaken before confidence could be placed in the first hypothesis. This work would also throw light upon the second postulate, which the author tentatively submits as an extrapolation for the case with a high compressive mean load.

The point has already been made that, given a suitable method of inspection, the engineer may have a considerable period at his disposal to devise, plan, and put into effect remedial measures, simply owing to the wide scatter in life from the first onset of fatigue cracking until it becomes widespread. However, another factor is the rate at which fatigue cracks will propagate, and the foregoing suggestion for future work would lead naturally into this second aspect of determining the rate of crack propagation under the stress conditions applicable.

A final aspect of evaluation which seems worthy of mention is, in effect, an elaboration of the foregoing point. Present-day design practice in regard to many aircraft components, particularly of secondary and tertiary structures, is that of the 'fail-safe' principle, *i.e.*, that the structure is sufficiently redundant to carry out its duty at only slightly reduced load factors even when it contains a number of obvious fatigue cracks. A similar philosophy could well be applied in the structural field given a suitable background of test data.

Repair

If a suitable inspection method is used there should be, in general, adequate time for detailed consideration of the most economic method of repair. However, a reasonably accurate assessment of the fatigue life of the repair is necessary before the economics can be determined. This, together with the need to produce effective but cheap repair schemes is probably the most urgent problem in the structural field at the present time. Several owners of welded heavy-duty gantry structures are currently faced with this problem.

In regard to repair methods, where these consist simply of making a new weld along the line of a fatigue crack, whether this is in the plate or weld metal, it is unlikely that the resulting repair will have a fatigue life matching that of the original construction. Indeed, where automatic shop welds made in the gravity position have to be replaced by overhead manual welds often under difficult conditions for the welder, the life of the repair is liable to drop to a small fraction of that of the original structure. A particular example of the repair of locomotive side frames by welding reported by British Railways[4] illustrates the difficulties of repairing fatigue cracks by simple welding procedures, even under workshop conditions. This report shows that a working life equal to the original construction could be attained only by replacing the whole of the fatigued zone with new plate material integrated into the old structure by welds placed in fields of low stress. What was found true in this particular case may well be true generally. Here, however, recent work by the B.W.R.A.[5] (which will be discussed later) on the beneficial effects of spot heating on the fatigue life of new constructions may, the author would suggest, be even more valuable when considered in relation to repair welding, which is often of necessity inferior to the original welding from the standpoint of fatigue.

In considering the repair, not only must its life be determined but also, if this does not carry the structure beyond its planned life, whether a further repair is feasible. On the basis of present knowledge, it would be unwise to attempt to prophesy whether zero, one, two, three or even more repair cycles in the working life will lead to true economy. However, by analogy with the aircraft field, it would seem that the answer will lie somewhere between one and four cycles.

Design

Design in this context refers to future structures and is treated under two headings. Firstly, the improvement of existing techniques, and secondly, the redeployment of present-day fabricating methods to produce more fatigue-resistant designs.

Locked-in stresses

Though work by Weck during the period 1945–1948 indicated that stress concentrations associated with design were the dominant factor in reducing the fatigue endurance of welded constructions below that of virgin plate, and that early fears in regard to the effect of intense locked-in stresses, which were at that time the subject of great interest, were not justified, the time has perhaps come to review our attitude to this question. Commercially attainable standards of welding have risen, and work on brittle fracture and with larger welded test pieces has thrown considerably more light on the question of locked-in stresses. A significant contribution to this reassessement is Trufyakov's work[2] which demonstrates the effect of locked-in welding stresses, and may perhaps put their importance relative to welding defects into better perspective at this juncture.

From the design viewpoint the significance of this is that it may lead to worthwhile improvements in fatigue endurance of welded construction by subtle yet simple design techniques by which the locked-in stress patterns are manipulated to advantage. These treatments may generally be referred to as "locked-in stress pattern improvement methods" (l.i.s.p.i.m.).

In the spring-making industry *lispim* (if the abbreviation is acceptable) is a time-honoured practice under the name "scragging". The fatigue endurance of springs is improved by the application of an overload two or three times after manufacture. It would seem that the same principles might be considered in relation to civil engineering structures. Where a structure, such as a crane gantry beam, is subjected to one dominant fatigue loading pattern, *i.e.*, the stress pattern which arises as the crane travels along, it would appear that if the crane is overloaded and then run two or three times over the length of the building, it can do no harm and will probably improve the fatigue endurance. As the wheels roll along the girder loaded to, say, 20% more than the greatest load that will ever be applied in service, in turn various zones in the girder will reach their highest stress. Fatigue cracks are most likely to occur in those locations where the stress range due to the working load is largely tensile and is additive to a tensile locked-in stress, which certainly in places will approach yield point magnitude. Under the overload, local yielding will occur at these points and will so modify the locked-in stress pattern that under subsequent working loads the total tensile stress will be reduced approximately by the extent of the overload. A general hypothesis may be stated in these terms: If a structure is subjected to one dominant fatigue loading pattern its fatigue endurance can be improved only by one or two applications of an overload of the same kind and in the same sense. Clearly, in the case quoted of gantry girders, where an overload test of the crane is already required, the cost of this would be negligible. It would merely involve running the crane once or twice up and down the length of the building, firstly with the proof load carried so as to produce the overload on one set of wheels and then with the crab transferred to produce the overload on the other side, scragging each gantry girder in turn.

While clearly the degree of stress pattern improvement attainable by scragging is limited by the amount of overload that it is practicable to apply without inconvenience or appreciable permanent set of the structure, if a method could be devised whereby, in locations where fatigue is likely, intense compressive locked-in stress patterns could be cheaply produced, then the beneficial effect would be much more powerful. The principle of applying locked-in compressive stresses to improve fatigue endurance has long been proved in practice by such applications as shot blasting internal combustion engine connecting rods and similar applications. The previously referred to work by the B.W.R.A.[5] concerns a simple technique for producing greater improvements in stress patterns than are possible by scragging, *i.e.*, by local thermal disturbance known as spot heating or by cold mechanical yielding. The principle of the first method is that the heat is applied to a local zone, which first yields in compression as it thrusts out as a result of expansion against the surrounding cold material. On subsequent cooling intense local tensile stresses are set up in this zone, and these are reacted by a surrounding complementary compressive stress field. The heat spot is positioned in relation to a fatigue-sensitive zone, such as the end of a fillet weld, so that this lies in the compressive stress field produced. An implication of the technique is, of course, that the centre of the heat spot itself has an unfavourable stress pattern but, being in plain unnotched plate, this adverse condition can be tolerated.

Not only can this simple but powerful technique assist future design but it can also, as has been previously indicated, be very helpful in dealing with problems of repair. However, it suffers from one drawback *vis-a-vis* the scragging technique. To be effective the heat spot must be properly positioned; indeed, in certain cases a spot in the wrong position can make matters worse. Reduced to the simplest terms the ideal position for a heat spot is approximately 2 in. from the origin of the fatigue crack (the precise distance depends on a number of variables) and lying so that its centre is in the direction of propagation of the fatigue crack. Scragging automatically sorts out each point in turn and cannot do harm provided that there is only one dominant fatigue loading.

Not only will the engineer need definite guidance on where to apply heat spots but, further, the technique will need to be developed so that a predetermined and metered quantity of heat can be applied at the right spots, and in so doing a telltale indication must be given so that subsequent inspection will ensure that the work has been properly carried out. Perhaps some development of stud or resistance welding techniques which put in a large quantity of heat locally, could be made which would leave a simple indication that would not in itself be a significant stress raiser.

Design development

Perhaps the most obvious line of approach to the development of more fatigue-resistant welded structures is towards structural forms which lend themselves to fabrication by the most fatigue-resistant of existing welding methods and, by the same token, avoid methods which are fatigue-sensitive. For example, recent work seems to show that manual, metal-arc fillet welds are much more prone to fatigue cracking

than automatic welds of the same kind. The substitution of automatic for manual arc welding implies development in design. Current practice on many structures is such that the clear runs necessary for automatic welding cannot be attained. A simple illustration is the question of stiffeners on plate girders. If the flange-to-web welds are to be made automatically the stiffeners must be fitted after and not before welding, and this involves differences in stiffener detail.

Since it is generally recognized that welding, in common with other methods of jointing, impairs the fatigue strength of the virgin material, a design approach that warrants further examination is that which endeavours to place the welds always in zones of low fatigue stress. Again, taking the top flange of a gantry girder as a specific example, the fatigue stresses that are currently causing fatigue failures of the flange-to-web welds are associated with wheel passes. Yet the advent of broad flange beams in this country, would allow the use of a split beam for the top flange so that the web-to-flange welds could be situated outside the fatigue stress field.

Whilst it may appear that such obvious design changes as this must produce structures considerably more fatigue resistant, experience has proved that very often what seems to be the better structure does not in fact turn out as expected. There is no substitute for experience, or perhaps accelerated experience in the form of laboratory tests.

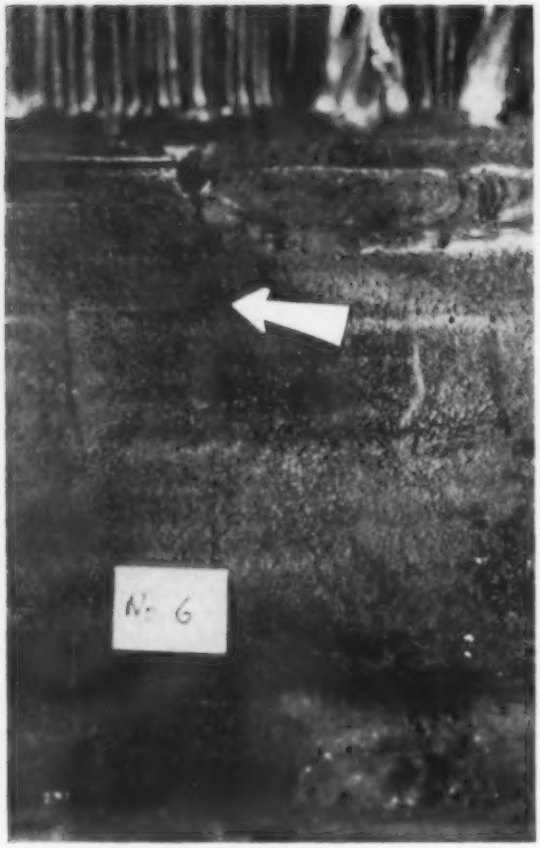
An aspect of the design problem that must be borne in mind when considering future research is the delicate question of the economic balance between a low first cost structure with recurrent maintenance charges and a higher cost structure with zero or reduced maintenance charges during its working life, the working life of most structures, such as dragline booms and welded constructions forming parts of a machine, being determined by obsolescence rather than wear and tear. While for relatively short life structures some extra initial capital cost to eliminate maintenance during the working life is often a worthwhile proposition, the position with civil engineering structures having a planned life of anything up to 100 years needs critical examination. In its simplest terms it may be argued that if £x extra are spent on a structure having a planned life of 25 years the true cost will be £4·5x, of 50 years £18x, or of 100 years £324x, based on compound interest at the rate of 6%. This steep rise in cost over long periods is often a dominating factor in establishing the most economic design, since it often outweighs such countervailing arguments as the high cost of repairs where these have to be carried out in a rushed manner to avoid loss of profit by interference with production, the effect of inflation which may double repair costs in 20 years, the vagaries of taxation and so on. Whilst it should not be over emphasized it is perhaps important for research workers to appreciate that in the field of welded structures with relatively long lives, only methods that incur small increases in capital cost for the sake of improving fatigue endurance are likely to be worth pursuing.

Accelerated Environmental Testing

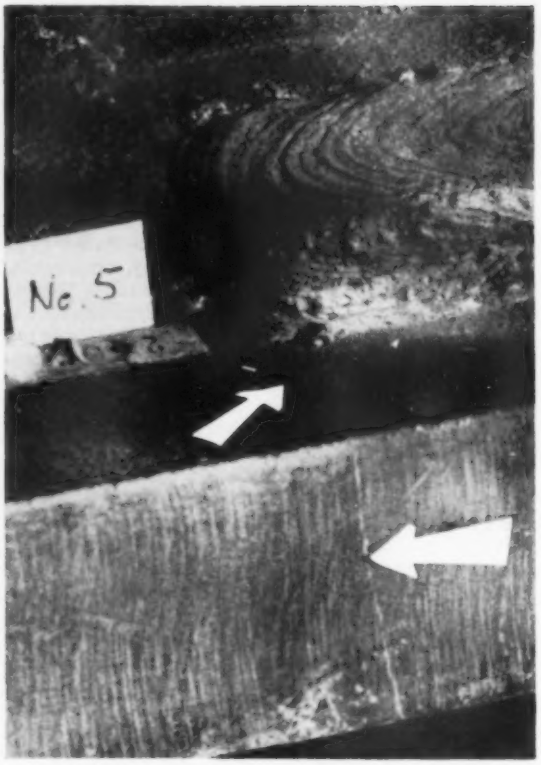
So far, an attempt has been made to outline a number of current problems, some of which, such as the maintenance problem, are urgent and others of which may perhaps allow of a decade for solution, and some lines which future research might follow have been indicated in general terms. However, it would be helpful if, at a symposium of this kind, some more concrete proposals could be submitted for discussion. If there were a common thread running through the problems outlined this in itself would indicate a positive course of action. The author believes that there is such a common thread.

On the maintenance side the critical problem of inspection using existing methods hinges on defining relatively small zones in the structure which have to be scrutinized—all-embracing visual inspection, though valuable, is clearly not enough. Though in a way axiomatic, it needs to be stated that the vast majority of fatigue cracks have occurred in places where they were not expected. There would appear to be no substitute for the fatigue testing of large-scale reproductions.

3—*Test rig for rail welds*



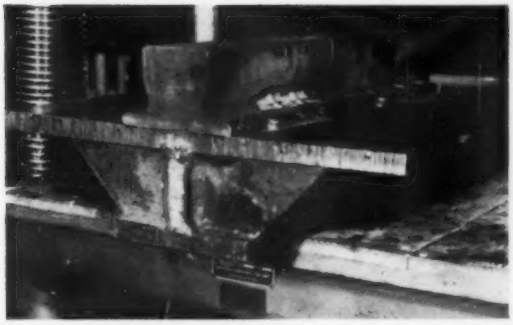
4—Crack in rail produced in test shown in Fig. 3



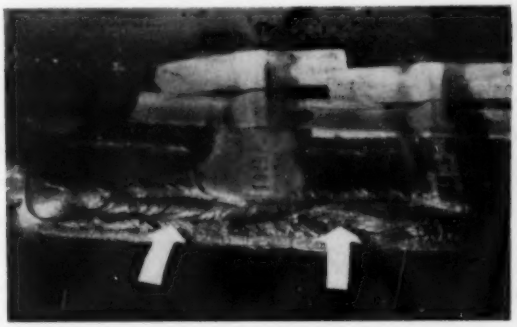
5—Crack in flange produced in test shown in Fig. 3

The question of crack evaluation—the study of the rate of propagation, whether cracks are self-inhibiting or possibly could be inhibited by spot heating or other techniques—demands approximately full-scale test pieces containing natural fatigue cracks. Also, in regard to repair, there are many methods which can be effectively tested and developed only if such specimens are available.

Turning to design development, whereas the pattern of locked-in stresses in any particular construction and the effects of these stresses on the fatigue endurance of welded details can be separately evaluated as in the past, large-scale fatigue tests would appear to be the most certain method of evaluating new designs and in particular the effect of simple changes, such as the use of spot heating, different welding methods, and so on. In regard to completely new designs that will stem from present-day knowledge, the author has no reason to believe that engineers or research workers will be more successful in predicting their vulnerable points than they have been in the past. As a generalization it may be stated that, in plate girder work, the bulk of research in the past decade has centred on the behaviour of the bottom flange, and that the bulk of trouble in practice has centred on the top flange. It is extremely easy to pick the wrong point or even the wrong loading. By way of illustration, some years ago the author was concerned with B.W.R.A. in evaluating the fatigue endurance of a gantry girder top-flange detail, which included a heavy rail intermittently welded to the top flange. The purpose was to ensure that in this then novel design, the fatigue endurance would exceed the rail change life, at which time the detail would start a new life on the occasion of rewelding. It was felt that the vulnerable points would be the ends of the intermittent welds, which would be severely stressed owing to the intense shearing load between the rail and the top flange as the girder flexed. This would be particularly severe at the end pair of welds, the rail being discontinuous but on a continuous gantry girder. An environmental test was decided upon and the form of test piece is shown in Fig. 3. Figures 4 and 5 show the fatigue cracks which were in due course produced in the laboratory, the shear being induced by resonating in bending the I section comprising a rail welded between two typical flange plates. On the basis of this test there was an ample margin of safety. However, five years' service produced several hundreds of fatigue cracks which were subsequently produced in a confirmatory environmental test shown in Figs. 6 and 7. These arose not from the shear loads that occurred at each crane pass, but from transverse bending effects at each wheel pass owing to lack of fit between the slightly concave bottom of the rail and the top flange of the girder which greatly exceeded that assumed in the design. This provides a good example of how easy it is to arrive at the wrong conclusion even



6—Second test rig for rail welds



7—Crack in carbon-block weld produced in test shown in Fig. 6

on the basis of a full-scale test which is not truly environmental. The two idealized tests together did eventually provide the whole story and gave 'bonus' information about further fatigue cracks to come, but had there been available an approximately full-scale environmental test rig during the design stage, the weakness would have been apparent then.

The foregoing seems to indicate that it may be profitable during the next decade to devote a considerable proportion of our resources to full-scale environmental testing or, better still, to create further facilities to add to our present more idealized and fundamental test programmes.

In considering a somewhat sweeping generalization of this kind, it is perhaps desirable to see how other industries, which may be a little in advance of the heavy steel fabricating industry in regard to fatigue, have tackled their parallel problems. For the past decade in the aeronautical field full-scale environmental testing has been regarded as a vital part of the chain of development testing necessary to ensure aircraft safety. In that sphere small-scale tests of idealized pieces or even on individual components have been proved by experience to be inadequate. In the automobile field the same conclusion has also been reached, and here virtually all the variables can be included. The M.I.R.A. test track includes every type of environment and puts prototype vehicles through them on an accelerated time scale.

In the structural field there is also a pioneer move in the same direction. British Railways Research Department at Derby is currently building facilities for full-scale environmental testing of bridge girders as a specific structure of wide concern from the fatigue standpoint.

The foregoing strengthens the author in his conviction that there is a great need to establish centralized environmental testing facilities for work on welded constructions, and in particular the immediate problem of the maintenance of welded gantry girders and the evaluation of newer forms of construction such as welded tubular structures. Since by virtue of their size the researches are expensive, centralization is necessary. Indeed ultimately we may have one central laboratory for the environmental testing of all civil engineering structures, whether of welded steel, concrete, or other materials, for not only are the capital resources required large but the direction and execution of this work depends mainly for its success upon the availability of rare and dedicated research workers with the requisite flare and it may be that these will be as difficult to obtain as the physical resources.

For the present, however, the immediate objective might well be the building of an environmental test rig for the fatigue testing of welded beams, with particular reference to the immediate problems of welded gantry girders and tubular structures which are being increasingly used under fatigue loadings. Such a testing rig would prove to be most valuable in the hands of an established team of research workers and under the aegis of an organization that would serve the whole welding industry.

Acknowledgments

The author gratefully acknowledges permission granted by The Steel Company of Wales Ltd., for the publication of information provided in Figs. 1 and 3–7. Further, he would thank his colleague, Mr. R. J. Braithwaite, for his valuable assistance in preparing this paper and for several of the ideas therein.

REFERENCES

1. "Design Aspects of Brittle Fracture". Contribution by E. M. Lewis. Admiralty Conference on Brittle Fracture, Cambridge, September, 1959.
2. V. I. TRUFYAKOV: *Avto Svarka*, 1956, No. 5 (translated in *Brit. Welding J.*, 1958, vol. 5, pp. 491–498).
3. "A Relation between Critical Alternating Propagation Stress and Crack Length for Mild Steel", by N. E. Frost. Preview Paper, Institution of Mechanical Engineers.
4. S. WISE: *Brit. Welding J.*, 1959, vol. 6, pp. 345–350.
5. T. R. GURNEY and L. NEKANDA TREPKA: *Brit. Welding J.*, 1959, vol. 6, pp. 491–497.

Programmed Fatigue Testing of Full Size Welded Steel Structural Assemblies

By J. G. Whitman,
M.ENG., PH.D., A.M.I.C.E., M.I.W.
and J. F. Alder, M.A., PH.D.

A newly developed fatigue machine is described which has been designed for testing complete welded high-tensile steel structures under programmed loading.

An S/N curve for this type of structure has been completed using constant amplitude testing, and interesting features are noted in the development of the fatigue cracks. A few tests have been run showing the effect of high initial loads approximating to two thirds of the yield point.

Some preliminary results are given of programmed tests, and their possible application to the cumulative damage problem of welded steel structures is discussed.

Introduction

THE WORK described in this paper is a part of an extensive research being conducted into the general problem of the fatigue of military bridges. This particular portion of the work is as yet in its early stages and the paper is only an interim report. It was considered, however, that the construction of the Panel Fatigue Testing Machine would be of interest to the Conference and that the results obtained so far are significant and well worth reporting. The authors trust therefore that they may be forgiven if they only tell half the tale, but this is slow work and it may be some time before the other half is completed.

The problem of the fatigue of military bridges becomes acute only when such bridges are used for civilian purposes, because it is only then that there is a possibility that the bridge may be used for long enough periods to cause such failures. Military bridges have to carry military loads and this is naturally their primary function. They must also be quickly assembled and easily transported, and these are over-riding considerations which make the saving of weight of first importance.

For this reason light constructions in welded high-tensile steels are often used with the highest possible stresses based on purely static considerations. As the structures have to be mass produced the simplicity and the economics of joint detail are also very important. Bearing these facts in mind and remembering that welded structural joints in high-tensile steels have been shown to be very little, if at all, better in fatigue than similar joints in mild steel, it is not surprising that the fatigue strength of the structures is found to be poor in comparison with their static strength.

When military bridges are used for civilian purposes they are usually 'de-rated', but the question of how much the permissible stresses should be reduced raises the whole issue of cumulative damage.

Cumulative Damage in Welded Structures

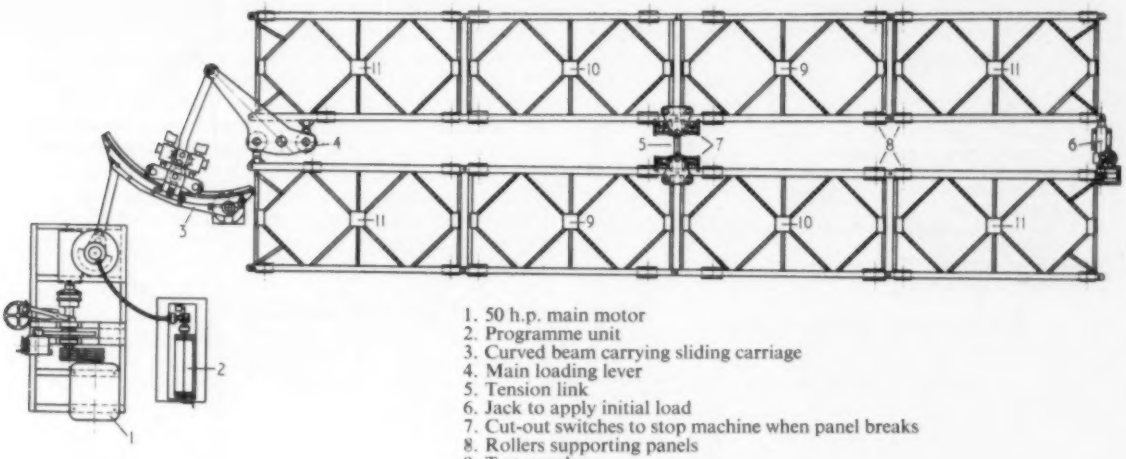
In general terms this problem arises as soon as the maximum design stress is allowed to exceed the fatigue limit, which is based on the total number of applications of stress to which a member may be subjected during a life time. In a fatigue testing machine such applications are all of one magnitude but in an actual structure, subject to normal day to day usage, such applications vary according to the proportion of the maximum design load that is being carried at any one time.

The practical issue arising from this difference between test and practice is how the 'mixed bag' of stresses that actually occur can be integrated to give some idea of the safe life of the structure. This is the problem resulting from the use of military structures for civilian purposes but its solution would also release civilian designers from the necessity of using the S/N curve as a limit for the maximum design stress for any given application. Once this limit has been removed much more economical use could be made of welded structures, and in particular the full advantage of the higher tensile structural steels could be realized.

Fatigue testing of full-size welded steel structural assemblies, as carried out at the Military Engineering Experimental Establishment, forms part of a wide attack on this problem at present in progress. Much of this work is in the very early stages and it would not be appropriate to discuss it here, but whilst the object of the more fundamental part of the programme is to find general solutions the object of testing complete welded structures is more limited and of a shorter term. For this work the primary object is one

Paper to be presented at a Symposium on Fatigue of Welded Structures to be held at Cambridge University on 29th March to 1st April, 1960.

The authors are members of the Military Engineering Experimental Establishment, Christchurch, Hants.


1. 50 h.p. main motor
2. Programme unit
3. Curved beam carrying sliding carriage
4. Main loading lever
5. Tension link
6. Jack to apply initial load
7. Cut-out switches to stop machine when panel breaks
8. Rollers supporting panels
9. Test panels
10. Strengthened panels in other test positions
11. Reinforced panels at ends of test girder

1—*General arrangement of panel fatigue machine (plan)*

of comparison of new designs with old. It is fortunate that there is in the Bailey Bridge an example of a military structure which has a long history of satisfactory service in all parts of the world, both in peace and war. There have, in fact, been only two examples of fatigue failures as far as the authors are aware, and both originated from gross manufacturing defects. Both occurred in bridges which had carried civilian traffic for a period of 8 or 9 years.

The Bailey Bridge therefore can be said to provide an acceptable standard, and the object of this section of the work is to compare this with the new designs using different materials and different joint details. To do this it was felt necessary to test complete structures and also to test them with mixed stresses as they occur in practice. In this way it was hoped to develop a yardstick, which will be evaluated from the Bailey Bridge and used to measure other equipment not as yet proved by experience. It was for this main purpose that the Panel Fatigue Machine was designed. There are, of course, many side benefits to be gained from this form of testing and, as will be seen, the results have practical significance besides the comparative value which was the first main object.

Panel Fatigue Machine

The machine applies repetitive loads to two test girders mounted horizontally on a rigid foundation, as shown in Fig. 1. It is powered by a 50 h.p. electric motor, which drives a short crankshaft through a flywheel, clutch, and a reduction gear box. When the machine is running, the crankshaft transmits oscillatory motion to the free end of a curved beam through a connecting rod (Fig. 2). The beam carries a sliding carriage, and a second connecting rod pinned to this carriage transmits the oscillation of the beam through a loading lever to the two test girders. A hand loading wheel and reduction gear are provided which may be engaged with teeth machined on the circumference of the flywheel.

Movement of the sliding carriage on the curved beam changes the magnitude of the load applied to the girders. Electric motors mounted on the carriage drive it along the curved beam by means of pinions engaging a curved rack.

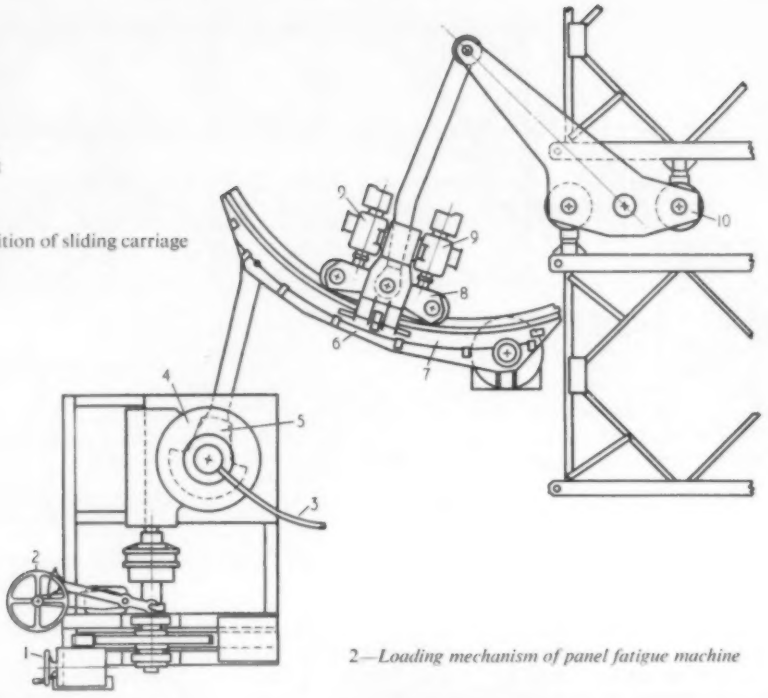
Any desired initial static load can be applied from a jack between the two test girders at the opposite end from the oscillating load lever. This initial static load and the fluctuating loads are measured by a tension link, fitted with strain gauges, which ties the two test girders at the centre of their span.

The magnitude of the fluctuating load can be set before a test commences or it can be varied by either a manual or an automatic control while the machine is running.

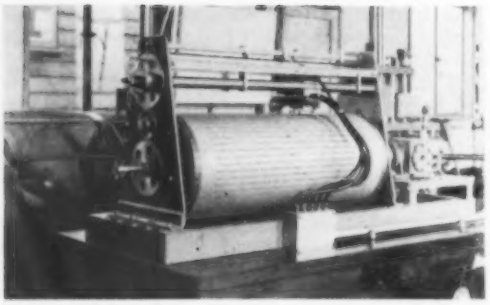
The automatic control consists of a drum geared to the main drive of the machine so that it revolves slowly in its frame when the machine is running (Fig. 3). Pegs are fitted at intervals in rows of holes in the drum, to form helices, positions being available every 20 cycles in a maximum period of 100,000 cycles. These pegs actuate micro-switches mounted on an overhead moving table which traverses the length of the drum as the helical line of pegs passes underneath. One switch controls the electric motors driving the sliding carriage on the curved beam, closure of the switch initiating movement to a new position determined by stops set on the beam. Two other switches operate a strain gauge recorder to obtain a record of the signal from the tension link for about 10 secs before and after a load change. Further switches on the moving table control the direction of the carriage, so that the load is increased or decreased by the next move and by the direction of rotation of the drum thus allowing a programme to be repeated.

In addition to the ordinary stops on the curved beam, which stop the travel of the carriage at predetermined points, special stops can be fitted for

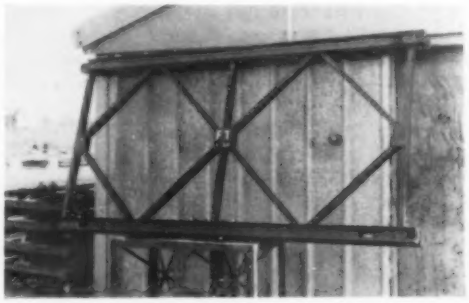
1. Hand loading mechanism
2. Clutch control
3. Flexible drive to programme unit
4. Gear box
5. Crankshaft
6. Curved beam
7. Bar carrying stops to control position of sliding carriage
8. Sliding carriage
9. Electric motors
10. Main loading lever



2—Loading mechanism of panel fatigue machine



3—Programme unit



4—Bailey Bridge panel made from high-tensile structural steel to BS.968 (min. yield stress 23 tons/sq.in.)

operating a switch to reverse the direction of travel of the carriage so that a single high load can be simulated. This is known as the 'quick reverse' setting and can be used at the maximum or minimum load levels or both.

A maximum deflection of 3 in. and a maximum load of 20 tons can be applied to the end of each girder. At present the girders under test, made up from Bailey Bridge Panels, are 5 ft 1 in. deep and 40 ft long. Girders 6 ft 6 in. deep and 50 ft long have also been allowed for in the design, and minor adaptations would permit structures of other dimensions to be tested.

Test Specimen

A general view of a Bailey Bridge Panel as used in the machine is shown in Fig. 4. Each test girder is made up of four of these panels, the end ones being specially strengthened as shown in Fig. 1.

The maximum stress occurs in the panel chords adjacent to the tension link at the centre of the span. Owing to the arrangement of the loading lever the stresses on the two sides of the machine differ by about 6%.

If all four panels at the centre are under test, as each breaks it has to be replaced to continue the test on the remaining unbroken panels, so producing a large number of panels partially tested at different stresses. To reduce the work entailed it was decided to use only two positions for testing and to strengthen the panels in the other two positions. The two panels being tested have the male jaw towards the tension link, so that normally all failures are at this position (which was considered to be the most prone to fatigue damage).

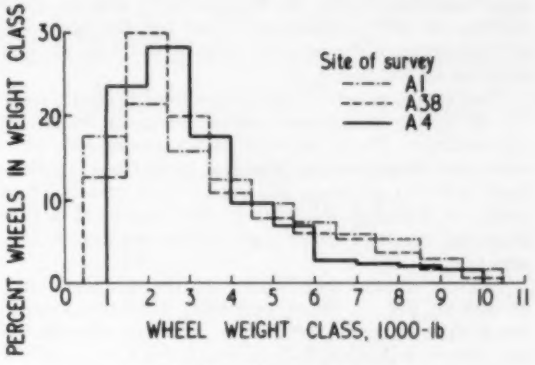
Load Pattern

Very little information appears to be available on the pattern of loading carried by a bridge under

normal civilian traffic. Most records of traffic flow, such as the Ministry of Transport census figures, show the distribution under the headings: cars, motor cycles, and lorries. Only the vehicles in the last category are likely to cause any appreciable stress in the bridge members, unless resonance vibrations are induced, but it is not possible in this type of count to sub-divide the vehicles according to load.

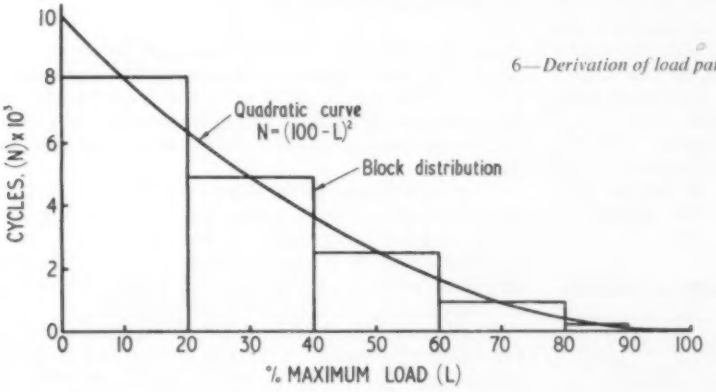
A few attempts have been made to weigh vehicles as they pass a check point but this involves considerable apparatus and may cause interference to the traffic flow. Figure 5[1] shows curves derived from this type of count.

It can be generally assumed that the number of vehicles causing the maximum design stress in bridge members is small compared to the total number of vehicles passing. A mathematical distribution was

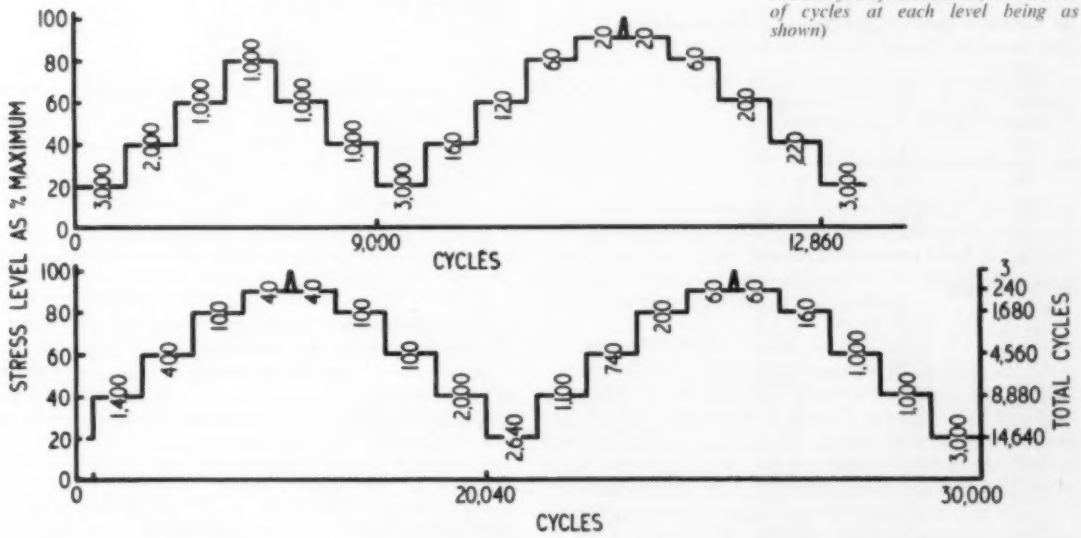


5—*Wheel load frequency diagram*[1]

6—*Derivation of load pattern*



7—*Programme used in tests (not to scale, each peak being at a different rate of rise and fall of stress level, the number of cycles at each level being as shown)*



therefore adopted for the first tests until actual records could be obtained.

It was decided that this assumed distribution would be of the form:

$$N = k(100 - L)p$$

where N is the number of cycles applied at a load level L is measured as a percentage of the maximum,

k is a constant which determines the length of programme,

p is the power of the curve (taken as 2 by comparison with Fig. 5).

Physical limitations of the machine reduced the number of load levels available for testing to about five or six. For convenience these levels were set at

approximately 20, 40, 60, 80, and 90%, and the quick reverse at 100% maximum load for the test. The smooth curve of the equation then takes on the stepped form as shown in Fig. 6.

This graph as calculated gave a total programme of 33,280 cycles, which was scaled down to 30,000 for convenience. The number of cycles at any load level was randomized within practical limitations for these early tests by allowing the load to rise and fall four times at different intervals in the course of a programme, three of which were to the maximum load and one to only 80%.

The form and distribution of the programme is shown in Fig. 7. After following this programme, when the control drum reverses, a mirror reflection of the same programme is followed from right to left so that the same pattern is repeated every 60,000 cycles.

A further limitation was that without increasing the span of the test girders the machine cannot be set to give a stress of less than 2½–3 tons/sq.in. As this is less than the fatigue limit, it was decided that this figure should for the time being be taken as the lowest significant load level, rather than 20% maximum load, which would normally be less than this value.

To obtain some actual data to compare with the above assumptions on traffic distribution several strain range counters are being fixed to various suitable road bridges. They will record the number of times the strain in a member changes by more than certain amounts. There are four levels of strain range, each of which can be adjusted to any desired value. By first taking readings with dial extensometers as known loads cross the bridge the most suitable ranges can be decided.

At present these gauges are fitted on five bridges and readings are being taken each month. On one bridge it has been possible to fix a gauge to a cross member under the deck so as to find out the relationship between the cycles applied to a deck member and the cycles applied to the main bridge chord.

It is intended that when results from these counters are sufficiently numerous to give any overall distribution picture the effect of these various patterns of loading will be investigated.

Table I

Results from normal fatigue tests with constant load amplitude

Specimen	*Maximum Normal Stress, tons/sq.in.*	*No. of Cycles to Failure*	*Remarks*
(a) Ordnance Panels (Used Panels taken from store)			
1A	11·4	34,404	
1C	10·6	66,334	
5A	9·0	150,991	
5B	8·5	178,871	
4A	7·2	146,062	
4B	6·75	236,829	
2A	5·75	307,536	
2B	5·4	482,176	
6A	4·7	1,861,268	
3A	4·4	1,809,038	
6B	4·4	2,180,485	Unbroken
3B	4·1	1,934,847	
(b) New Panels			
G14A	13·2	14,867	
G15A	13·0	19,635	
G14B	12·4	36,827	
G15B	12·2	34,784	
G1A	11·4	25,136	
G1B	10·7	41,751	
G8C	9·6	71,565	
G3A	9·3	77,644	
G3B	8·7	65,414	
G4A	7·3	322,807	
GP2	7·3	220,010	
GP3	7·3	232,316	
G4B	6·9	287,020	
G2A	5·7	680,576	
G2B	5·3	1,069,781	
TAG2	10·2	57,647	Panels tested in other positions usually filled with strengthened panels Failure at female jaw.
TBG1	6·8	210,948	

Table II

Results from tests including a single initial high load

Specimen	*Nominal Pre-load Stress, tons/sq.in.*	*Nominal Test Stress, tons/sq.in.*	*No. of Cycles to Failure*
G7A	15·6	10·2	89,673
G7B	14·6	9·6	106,400
G8A	16·1	9·6	118,974
G8B	15·0	9·0	161,470
G5A	16·3	7·6	853,291
G6A	15·4	7·3	516,875
G5B	15·2	7·1	550,507
G6B	14·4	6·8	1,020,277
G9A	16·1	6·6	856,960
G9B	15·0	6·2	1,043,188
G10A	16·1	5·3	1,166,751
G10B	15·0	5·0	1,666,154 (Unbroken)

All specimens were new panels

Results

The tests carried out so far can be divided into three main types:

(*a*) Normal fatigue tests applying a pulsating load of constant amplitude until failure occurs

(*b*) Tests similar to (*a*) but preceded by the application of a single high load of approximately the maximum likely to occur in service

(*c*) Tests using a mixture of load amplitudes, which may be either (i) programmed to some pre-determined sequence, or (ii) in large blocks of each amplitude as the machine was used.*

The results from these tests are listed in Tables I, II, and III and shown graphically in Fig. 8.

In all cases the lower stress was a little over zero up to approximately ½ ton/sq.in. so as to take up any clearances and to avoid chatter in the test girders.

Discussion

There are several points of interest arising from the results that have so far been obtained from the Panel Fatigue Machine.

* The system of testing two specimens simultaneously employed in the machine means that one is left unbroken when the other fails. Certain panels have therefore been kept in reserve so as to 'run out' the unbroken member of the pair. These reserve panels have in due course accumulated a rather peculiar form of programming and those that have failed under this loading are shown in Table III (*b*).

Table III

Results from tests with varying load amplitudes

Specimen	Maximum Nominal Stress tons/sq.in.	No. of Cycles at Stress* n	Expected Life at Stress N	Ratio $\frac{n}{N}$	$\Sigma\frac{n}{N}$	Total Cycles in Test
(a) Pre-determined programme. (Quadratic type, see Fig. 7)						
G12A	3·3	195,100	assumed infinite	0		
	5·8	118,500	520,000	0·228		
	9·0	60,400	90,000	0·671	2·1	399,460
	12·1	22,070	24,000	0·920		
	13·9	3,270	13,000	0·252		
	15·2	120	9,000	0·013		
G12B	3·1	271,300	assumed infinite	0		
	5·4	164,800	680,000	0·242		
	8·4	84,100	120,000	0·701	2·2	555,738
	11·3	30,490	32,000	0·953		
	13·0	4,880	17,000	0·287		
	14·2	168	11,800	0·014		
G13A	2·9	223,000	assumed infinite	0		
	5·1	135,300	850,000	0·159		
	8·3	69,400	125,000	0·555	1·8	456,795
	11·5	25,360	29,500	0·859		
	13·2	3,600	16,000	0·226		
	15·0	135	9,400	0·014		
G13B	2·7	269,900	assumed infinite	0		
	4·8	163,900	1,130,000	0·145		
	7·8	84,100	160,000	0·526	1·7	553,492
	10·8	31,110	40,000	0·778		
	12·4	4,320	21,300	0·203		
	14·1	162	12,000	0·013		
G16A	3·6	603,200	assumed infinite	0		
	5·3	365,000	715,000	0·511		
	7·0	188,000	250,000	0·752	02·7	1,235,31
	9·9	68,900	59,000	1·169		
	11·1	9,840	35,000	0·281		
	12·4	370	21,300	0·017		
G16B	3·4	644,200	assumed infinite	0		
	5·0	391,600	940,000	0·417		
	6·6	201,700	315,000	0·640	2·4	1,322,357
	9·3	73,900	78,000	0·948		
	10·4	10,560	48,000	0·220		
	11·6	397	28,500	0·014		

Specimen	Maximum Nominal Stress tons/sq.in.	No. of Cycles at Stress* n	Expected Life at Stress N	Ratio $\frac{n}{N}$	$\Sigma\frac{n}{N}$
(b) Two or more load amplitudes applied in 'blocks'					
P2	11·3	28,918	32,000	0·904	
	5·75	175,410	560,000	0·314	1·6
	4·4	125,809	1,800,000	0·070	
	9·0	26,293	90,000	0·292	
P3	7·2	90,767	230,000	0·395	
	3·6	62,435	assumed infinite	0	1·0
	9·0	1,587	90,000	0·018	
	4·7	319,217	1,250,000	0·255	
	13·2	5,021	16,000	0·314	
GP1	11·4	16,615	31,000	0·536	
	5·7	389,205	550,000	0·708	
	8·7	12,230	105,000	0·117	2·8
	6·9	35,787	280,000	0·128	
	7·1	302,784	240,000	1·262	
	7·3	8,464	220,000	0·038	
GP4	7·3	42,612	220,000	0·194	
	10·2	16,727	52,000	0·322	
	9·0	29,069	90,000	0·323	2·1
	6·6	186,228	315,000	0·591	
	5·3	499,403	730,000	0·684	
TAG1†	7·3	166,681	220,000	0·756	0·9
	10·2	8,051	52,000	0·155	Failure at female jaw
TBG2†	6·8	63,980	285,000	0·225	0·75
	9·6	35,135	68,000	0·517	Failure at female jaw

* Total cycles at each stress level.
(i) The loads applied are distributed in as random a manner as practicable as described earlier.
(ii) All specimens were new panels.
(iii) Stresses are shown in the order applied.
(iv) Panels P2 and P3 were from Ordnance, the others were new.

† Panel TAG1 had a single loading to give a nominal stress of 15·6 tons/sq.in. between the two blocks of repeated loading, and panel TBG2 a single loading to give a nominal stress of 14·6 tons/sq.in.

Location of fatigue fractures

As has been emphasized earlier, the test panels have been arranged so as to expose the welded assembly at the male jaw to the maximum stress.

Failure, in fact, occurred most frequently at the sway brace slot, as shown in Fig. 9. This would suggest a maximum stress concentration at this point, but there are many welds of almost equal severity in a structure of this kind. On two occasions the loading rig was re-arranged so as to expose the female jaw assembly to the maximum stress. These failures also occurred at the sway brace slot, but in this case there is not the added complication of a transverse weld. These results are plotted in Fig. 8 and fall well within the general scatter band.

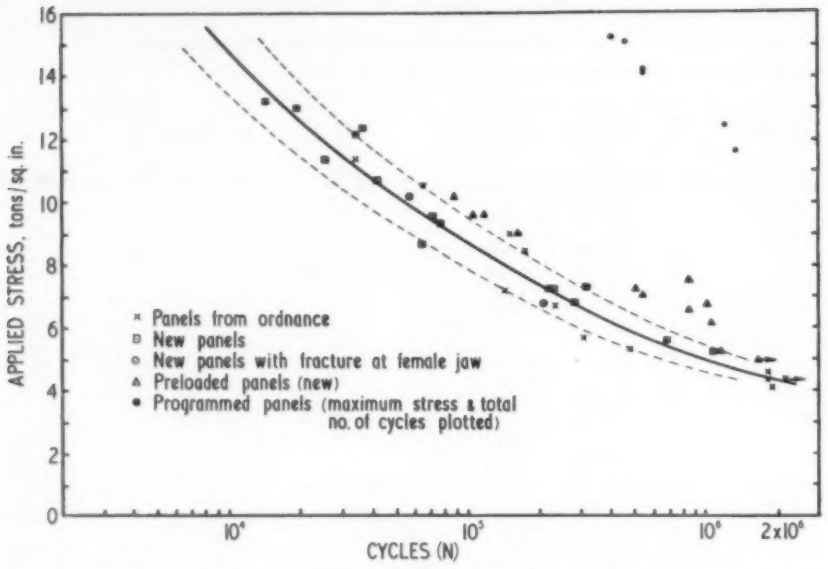
In the panels not used as test specimens but as part of the loading rig, fatigue failures have in fact occurred at several different positions, as shown in Fig. 10. These have been strengthened and repaired by welding as they occurred, but the rate and order of their occurrence would suggest the same general level of fatigue strength with the weld acting as the deciding factor for the occurrence of fatigue failures.

Development of fatigue cracks

One of the most significant facts so far emerging from this work has been the mode of development of the fatigue fractures. Complete severance of the tension chord has been taken as the criterion for failure since, besides being experimentally convenient, this is justifiable by the fact that the panel continues to carry its full load until final fracture occurs in this way.

The development of these fatigue fractures is illustrated in Fig. 11; the slow rate of development occurs whether the tests are programmed or of constant amplitude. The normal process of failure is for a number of small but easily visible cracks to form before the further development of one, not necessarily the first, leads to a final failure.

The rate of growth of a crack is usually fairly rapid


APPLIED STRESS, tons/sq. in.
CYCLES (N)
Panels from ordnance
New panels
New panels with fracture at female jaw
Preloaded panels (new)
Programmed panels (maximum stress & total no. of cycles plotted)

8—*Results of tests. Dashed curves are at 2/3 and 3/2 life of mean curve*

in the first stages and then very much slower, giving time for other cracks to form. In several instances seven separate cracks had developed at a joint before final failure occurred.

This whole process would rarely take less than 100,000 repetitions to complete, and in some cases (Fig. 11) would take over 500,000 repetitions. This long time of development is a fact of considerable practical value, for clear evidence of the on-set of failure exists for a considerable time before the failure actually occurs.

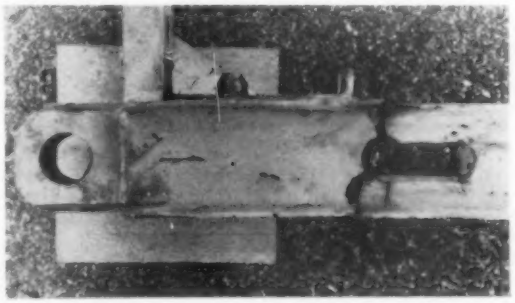
The variation in the rate of spread of these cracks is probably accounted for by the internal stress fields that exist in all welded structures. The initial stages of crack propagation would presumably be through a residual tension field at and close to the weld, and when the crack has passed through this into the compensating compression field the rate of propagation would slow down and might sometimes stop altogether.

Basic S/N curve

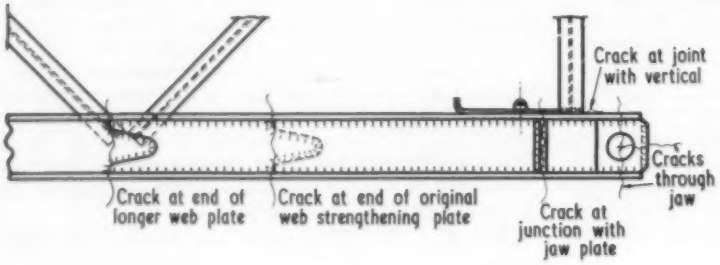
The first tests to be carried out with this machine were straight repeated-load tests without programming, so as to establish the basic S/N curve for this structure. Fifteen new panels were used and also twelve panels drawn from an Ordnance Store. These latter panels have in all probability had some previous use and incidentally have at some time in their life been allowed to corrode to a considerable extent. It is interesting to note that the fatigue points from all these specimens fall within the same scatter band.

There is unfortunately no way of determining the previous stress history of the twelve Ordnance panels, and the fact that none of them show any reduction in life may simply mean that in the past they have not been subjected to a significant number and magnitude of stresses. On the other hand, it is a little surprising that out of twelve such panels selected in this way none showed any evidence of significant stress history. This result can at least be regarded as one warranting further investigation.

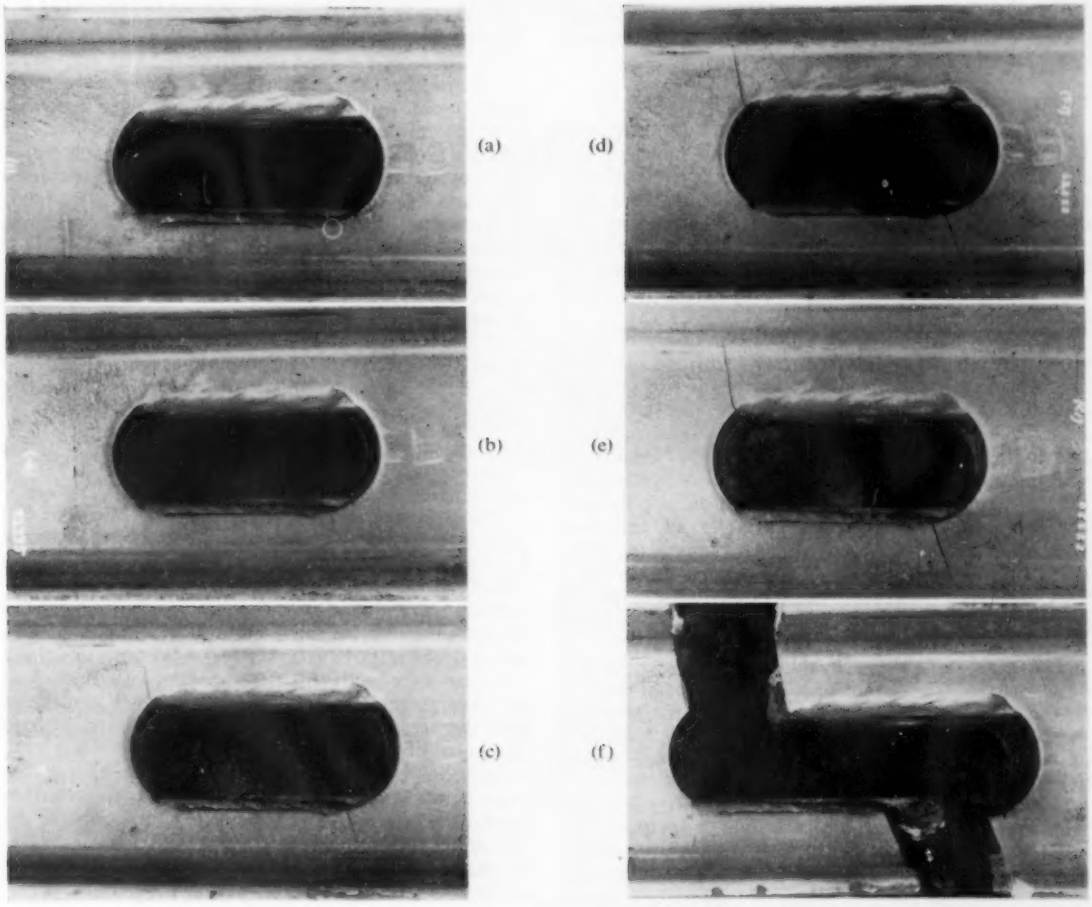
It was therefore decided to make further use of this type of panel for these fatigue tests. If any unduly short life were to appear it would be evidence of previous fatigue damage. If no such short life is re-



9—*Normal form of fracture (panel G 1 A) due to cracks spreading from the sway brace slot. Another crack of considerable size is at the lower left-hand corner of the slot, and a small one at the lower right-hand corner*


Crack at joint with vertical
Cracks through jaw
Crack at end of longer web plate
Crack at end of original web strengthening plate
Crack at junction with jaw plate

10—*Failure points observed near female jaw of strengthened panels*



11—*Development of fatigue cracks during a test:* (a) *First crack just visible (430,000 cycles);* (b) *second crack growing (650,000 cycles);* (c) *two cracks approx. equal in length and growing (800,000 cycles);* (d) *cracks (not visible) also appeared in lower channel* (1×10^6 *cycles);* (e) *just before failure* ($1{\cdot}2 \times 10^6$ *cycles);* (f) *failure of whole chord* ($1{\cdot}235 \times 10^6$ *cycles*)

vealed by these further tests at least good use will be made of cheaper specimens! Further speculation is not warranted.

The fatigue limit of 4–4½ tons/sq.in. for 2,000,000 repetitions is not surprising, bearing in mind the known effect of discontinuous welds and the evidence of some further stress concentration at the points of failure. Such results as this are, of course, a further reminder of the lack of benefit from the use of welded high-tensile steels, if fatigue testing at constant amplitude is to be used as a measure of strength.

Initial loads

Heywood[2] has shown that an increase in fatigue life of aluminium alloy structures from approximately 1½ to 4 will result from a high static stress applied before the commencement of a fatigue test. On the other hand some recent work by Nottingham University[3] has shown that with turned low-alloy steel specimens containing a transverse hole, initial high static stresses up to the yield point have no effect on subsequent fatigue life. Initial stresses above the yield point were found to give a considerable increase in scatter but the general effect is damaging, *i.e.*, subsequent fatigue life is shortened.

It is intended to explore this part of the cumulative damage problem in some detail as it effects welded steel structures. The machines intended for this work, however, are not yet available, so that, as a preliminary experiment, several tests were run in the Panel Fatigue Machine in which a pre-stress was applied of the order of the maximum ever likely to occur in service (16 tons/sq.in.). These points are also plotted on Fig. 8. There is a slight improvement in life, of the order of 1½ times, when the subsequent test is run at 9–10 tons/sq.in., and approximately three times when run at 6½–7½ tons/sq.in.

It is not thought that there would be any appreciable increase in fatigue limit as the result of the pre-load although the point on the diagram shown as unbroken had in fact not developed a crack when the test was stopped, and there are far too few results to draw any definite conclusion on this point.

The difference in behaviour between the turned

specimens and the welded structures is possibly associated with relief of internal stress in the latter as a result of the applied overload.

Programmed tests

As has already been explained, the programmed test was the object of the design of this machine, but the comparison of such tests with the normal S/N curve may have considerable significance and may even offer a more direct solution to the problem.

For the purpose of this paper it is regretted that only a few of these results are at present available, but though they are still in the very early stages they are of considerable interest.

The steps that are being taken to obtain records of stress patterns to which a variety of bridge members are subjected has been mentioned but it will be some time before representative information has been accumulated and, in any case, it is understood that such distribution will vary according to the locality in which the bridge is situated. Quite obviously considerable generalization of such information is necessary for test purposes, and the variables of the load patterns must be assessed for this purpose by their effect on fatigue life.

A start has therefore been made with a purely empirical stress pattern, which has been described earlier and is shown in Figs. 6 and 7.

The minimum stress level of $2\frac{1}{2}$–3 tons/sq.in. has been assumed, for the purpose of this series of tests, to be the lowest stress level of significance to fatigue in these joints. The actual significant stress level is a matter of considerable practical importance and is being investigated separately.

The order of application of this load pattern has been randomised as far as is practicable for these initial tests, and although this is perhaps not as mixed as might occur in practice, it is felt that it is sufficiently so to obviate the effect of order of loading, which has been shown by a number of workers to exist in two level testing.

The lowest stress of this load pattern is below the fatigue limit for 2×10^6 repetitions, so that these stresses do not add to the total of the cumulative cycle ratio. Nevertheless, these values so far obtained (Table IIIa) are all greater than 1 and vary from 1·7 to 2·7. As is well known this value was originally suggested by Miner[4] to approximate to unity.

The results from these programmed tests have also been plotted in Fig. 8 on the basis of the total number of repetitions against the maximum stresses. Provided that some minimum condition can be established for the variations of load pattern within the practical limits, this form of plotting might provide useful information for design purposes in that it would give the maximum design stress range for the expected number of applications. On this basis these few results show a life of 4×10^5 repetitions for a maximum working stress range of 15 tons/sq.in. and a life of $1{\cdot}2 \times 10^6$ for a maximum working stress range of 12·5 tons/sq.in. This method of presentation certainly emphasizes the suggestion that higher figures can be used for maximum working stresses than the fatigue limit for the appropriate number of repetitions.

In regard to the programmed tests shown in Table IIIb in which blocks of two or more stresses are applied, there are again too few results to draw any definite conclusions. It will, however, be seen that the cumulative cycle ratio varies from 0·75 to 2·8, which range overlaps the ratios so far obtained for the specimens tested with programmes assumed to represent service conditions.

It is also interesting to note that the greatest cumulative cycle ratio so far obtained is 2·8 from specimen GP1, and that this specimen was given initially a block of repetitions of the highest stress of the programme. Similarly the lowest cumulative cycle ratio of 0·75 comes from specimen TBG2, which was given initially a block of repetitions of the lowest stress of the programme. These admittedly isolated results do not agree with the findings of J. B. Kommers *et al.*,[5] that high initial stresses result in cumulative cycle ratios less than unity and low initial stresses give cumulative cycle ratios greater than unity in two level testing.

Conclusions

The principle of the Panel Fatigue Machine has been established. The machine has, in fact, had very few teething troubles and works smoothly and reliably.

The rate of spread of a fatigue crack in this type of structure has been shown to be slow and should give ample time for its detection before a failure takes place.

Initial over-loads of a value approximately $\frac{2}{3}$ of the yield strength result in a slight though significant increase in the subsequent fatigue life of welded structures of this type.

Although only a few programmed tests have so far been completed it already seems likely that further work will show that very little, if any, reduction of the maximum working stress may prove to be necessary to meet fatigue conditions for welded steel road bridges.

Acknowledgments

The original idea for this type of structural testing and the concept of the design of the Panel Fatigue Machine was due to Professor J. A. Pope, and the authors are indebted to him for his continuous interest and helpful advice. They also acknowledge the encouragement given by the Director and their indebtedness to various groups within the Military Engineering Experimental Establishment, especially the Drawing Office (particularly Mr. I. Davies) for much of the detail design, the Workshop for almost the whole of the fabrication of the machine, and the Electrical Section for the control circuits.

The illustrations are Crown Copyright reserved, and are reproduced with the permission of the Controller, H.M.S.O.

BIBLIOGRAPHY

1. J. J. Trott and P. J. Williamson: "An apparatus for measuring, classifying and counting the wheel loads of moving vehicles". D.S.I.R., Road Research Laboratory, Research Note No. RN/3230/JJT.PJW. April, 1958.
2. A. B. Heywood: "The effect of high loads on fatigue". I.U.T.A.M. Conference on Fatigue, Stockholm, 1956, p. 92.
3. Unpublished work carried out by Nottingham University as part of the wider and more fundamental investigation into the Cumulative Damage Fatigue Problem.
4. M. A. Miner: *J. Applied Mechanics*. 1945, vol. 12, p. *A*159.
5. J. B. Kommers: *Proc. Soc. Exp. Stress Analysis*, 1946, vol. 3, p. 137; *Proc. A.S.T.M.*, 1945, vol. 45, p. 532.

SYMPOSIUM ON FATIGUE OF WELDED STRUCTURES

Fatigue of Welded Joints in High-Strength Steels

By J. E. Stallmeyer and W. H. Munse

A discussion is presented of the fatigue strengths of various types of welded joint in alloy structural steels. The steels covered in this discussion have a range of ultimate strengths from 75,000 to 150,000 lb/sq.in. (33½ to 67 tons/sq.in.). Transverse and longitudinal butt welded joints are discussed as well as longitudinal fillet and the tee-fillet welded joints. The discussion covers the fatigue strength properties of such joints and the various factors which may have an important bearing on these properties.

Introduction

THERE has been and is currently a growing interest in and awareness of the importance of fatigue in structures fabricated from high-strength steels. To understand this increased attention it is necessary to review briefly some of the factors that should be considered by the designer. These factors deal with economy, allowable design stresses, fabrication procedures, weld treatment, and applied stress cycles.

High-strength steels are being used at an ever increasing rate because of the higher static strength attained. In almost all specifications an increase in design stress is permitted, based primarily on an increase in the yield point of the material. This increase in design stress results in a proportionate saving in material weight and generally a saving in material cost. There may also be a saving in fabrication costs because of the thinner materials involved.

The design specifications, however, usually require a reduction in the allowable stress for those members which are subjected to repeated cycles of stress variation. This reduction can remove the economic advantage if the members are subjected to a sufficiently large number of repetitions of stress variation to require such a reduction in the allowable stress. The designer is therefore faced with the problem of estimating the number of stress cycles expected during the life of the structure.

In addition to these problems the designer must choose from a variety of materials, a large number of electrodes, several different processes, and a whole series of joint configurations. The materials suitable for a specific application may be similar but may, for one reason or another, not produce joints with the same S/N relationships. In general, the effect of the type of electrode on fatigue behaviour is insignificant, provided that the electrode is compatible with the material and the process used, except as it affects the final geometry of the joint. The different welding processes, manual or automatic arc welding, should differ little in the soundness of their welds if properly deposited. However, this factor, the welding process, can be eliminated by the use of good shop practice and sound procedures. Different joint configurations are usually dictated by many design conditions and fabrications, the manner in which the welding must be carried out, and the facility with which a sound welded joint can be produced.

Finally, a few words are in order regarding the applied stress cycles in structures subjected to fatigue. High-strength structural steels are generally used where there are significant dead load stresses and where the range of applied stress in the stress cycles is relatively small. High-strength steels have also found wide application in the pressure vessel field, in cases where the number of repetitions may be quite low but in which the fluctuation in stress may be quite large.

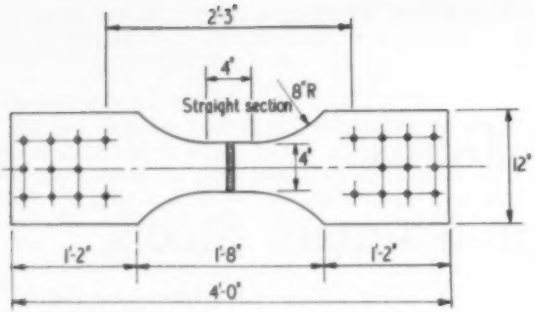
It is impossible to discuss all the forementioned subjects in detail. Indeed, in some areas there is an insufficient amount of data to do more than provide a guide for use in combination with engineering judgment, tempered by a knowledge of the structural integrity required. This paper then will deal with those areas in which the data are most revealing.

Transverse Butt-Welded Joints

By far the largest number of tests have been carried out on transverse butt-welded joints. The configuration of the test specimens most generally used is shown in Fig. 1. In general, the principal variations in geometry have been in the weld, the width of the test section, and thickness of the material. Although the length of the specimen has also varied its effect is not significant. In addition to the differences in the overall geometry of the test specimens a variety of configurations for the joint detail have been studied. One of the

Paper to be presented at a Symposium on Fatigue of Welded Structures, to be held at Cambridge University on 29th March to 1st April, 1960.

Dr. Munse is Professor of Civil Engineering, and Dr. Stallmeyer is Associate Professor of Civil Engineering, in the University of Illinois, Urbana, Illinois, U.S.A.



1—*Typical test member with transverse butt weld*

most common types of welded connection studied has been the transverse double-V butt weld of flat plates in the as-welded condition.

Several major variables have been included in the various programmes; base metal, electrode type, joint configuration, stress cycle, welding process, and pre- or post-welding treatment. Each of these variables and their effect on the fatigue behaviour will be considered in more detail.

Base metal

The steels included in the various studies range in ultimate strength from approximately 75,000 to 150,000 lb/sq.in. (33½ to 67 tons/sq.in.) and include most of the steels for structural applications. Some of the steels are hot rolled, while others, particularly the higher strength alloys, are heat-treated after rolling. Typical properties for some of the American steels referred to are given in Table I.

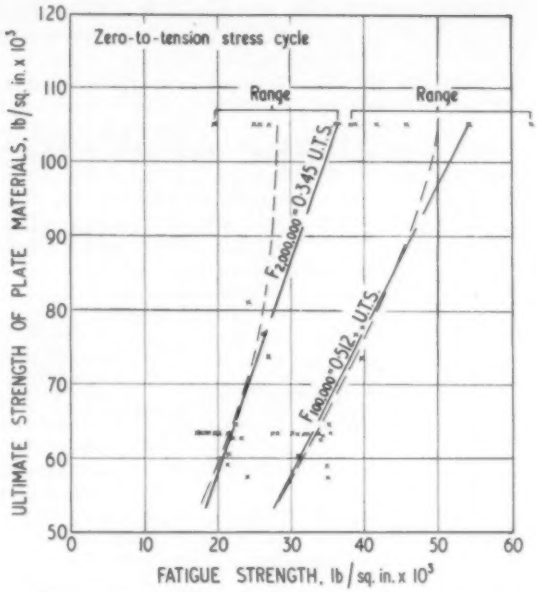
As a result of a complete summary and analysis of fatigue data for welded joints, which is currently being completed, it has been observed that in the as-welded condition the fatigue strength of butt-welded joints, on a zero-to-tension stress cycle, increases with the strength of the base metal. A general summary of the analysis of the test data reviewed is shown in Fig. 2. This diagram shows the results for the lower strength steels as a basis for comparison. The straight lines for fatigue lives of 100,000 cycles and 2,000,000 cycles represent the relationships

$$F_{100,000} = 0{\cdot}512 \text{ U.T.S.}$$

and

$$F_{2,000,000} = 0{\cdot}345 \text{ U.T.S.}$$

If one considers the relationship for a fatigue strength of 2×10^6 cycles the following points should



2—*Relationship between fatigue strength of double-V transverse butt-welded joints with reinforcement on and ultimate strength of base plates*

be observed. For the range of ultimate tensile strength from 60,000 to 80,000 lb/sq.in. (27 to 36 tons/sq.in.) the previously mentioned relationship appears to be fairly accurate. However, above 36 tons/sq.in. the test results indicate that the average value for $F_{2,000,000}$ does not change significantly. At the higher ultimate strengths the scatter in test results is extremely great. It would appear that the high-strength steel is much more sensitive than the lower strength structural grade steels and is affected markedly by variations in geometry and cross-section of the weld, lack of penetration, porosity, and heat or mechanical treatments.

For a fatigue life of 10^5 cycles the data indicate that the relationship between fatigue strength and ultimate tensile strength is somewhat more consistent. It is again true for this case that the higher strength steels show a greater scatter in test results.

A summary of the variations in average fatigue strength with base metal is presented in Table II. The percentage increase in fatigue strength for the A-242 steel is approximately equal to the increase in static strength. For T-1 steel such an increase in fatigue strength cannot be shown; however, the range for this

Table I

Typical properties of low-alloy structural steels

Steel	*Composition, %*								*Yield strength, lb/sq.in.*	*Ultimate strength, lb/sq.in.*	*Elong. on 8 in., %*	*Red. in area, %*
	C	*Si*	*Mn*	*P*	*S*	*Cu*	*Ni*	*Cr*				
A-242*	0·20	0·100	1·08	0·010	0·025	0·38	0·60	—	51,300	76,900	26·5	58·0
Japanese H.T.	0·16	0·500	1·20	0·013	0·017	—	—	—	49,400	80,400	22·0	—
A-94 (Silicon)	0·30	0·310	0·72	0·025	0·035	0·220	—	—	51,500	83,900	22·5	51·2
T-1	0·12	0·220	0·75	0·016	0·026	0·32	0·79	0·62	94,700	106,700	14·0	59·5
A-8 (Nickel)	0·32	—	0·75	0·025	0·070	0·22	3·51	—	—	—	—	—

* ASTM Designation

Table II

Effect of material on average fatigue strength of transverse butt welds: as welded

Material	*Increase in tensile strength %*	*Fatigue strength at 10^5 cycles lb/sq.in. $\times 10^3$*	*Percent. increase over carbon steel*	*Fatigue strength at 2×10^6 cycles lb/sq.in. $\times 10^3$*	*Percent. increase over carbon steel*
Carbon or structural (U.T.S. 61,000 lb/sq.in.)	—	32·3	0	20·2	0
A-242 (U.T.S. 76,000 lb/sq.in.)	+24·6	39·1	+21	26·5	+31
Silicon (U.T.S. 81,000 lb/sq.in.)	33·0	—	—	24·0	+19
T-1 (U.T.S. 105,000 lb/sq.in.)	72·0	38·0–62·4	+18 to +93	19·5–36·4	−3 to +80

high-strength steel is such that it appears that an increase in fatigue strength comparable to the increase in ultimate strength may be possible. It would seem that with a better understanding of the factors affecting the fatigue strength of a butt-welded joint in high-strength steels, sizeable increases might be realized.

For transverse butt-welded joints in the as-welded condition the following conclusions are fairly well substantiated on the basis of test data. The particular application of high-strength steels where the number of repetitions of stress is relatively small would appear to have great merit. When there are very many repetitions of stress there appears to be little advantage in using high-strength steels. It appears that any small discontinuity in the welded joint, regardless of how minor it may seem, will eventually form the nucleus for a fatigue crack. Once the fatigue crack is initiated in a high-strength steel it usually propagates somewhat more rapidly than it would in a lower strength steel. The net result then is that the two types of steel resist the same number of cycles of stress repetition before complete failure.

Stress variations

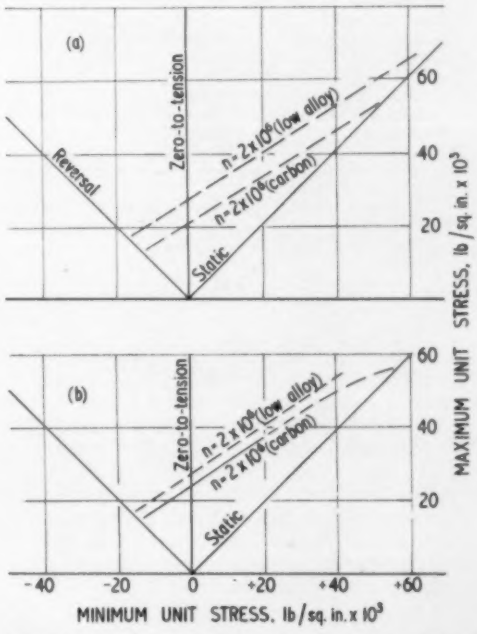
The previous discussion has been based on test results obtained on a zero-to-tension stress cycle. To discuss fully the merits of the use of high-strength steel it is necessary to consider its properties, relative to ordinary structural steel, when subjected to different stress cycles. The most convenient form for presentation of such data is in the form of modified Goodman diagrams. Such diagrams for two different types of joint with transverse butt welds are shown in Fig. 3. For comparison these diagrams also present the same relationships for ordinary structural steel.

These diagrams suggest that the greatest advantage of high-strength steels lies in their resistance to stress cycles in which the stress varies only a relatively small amount when the maximum value of tension is high.

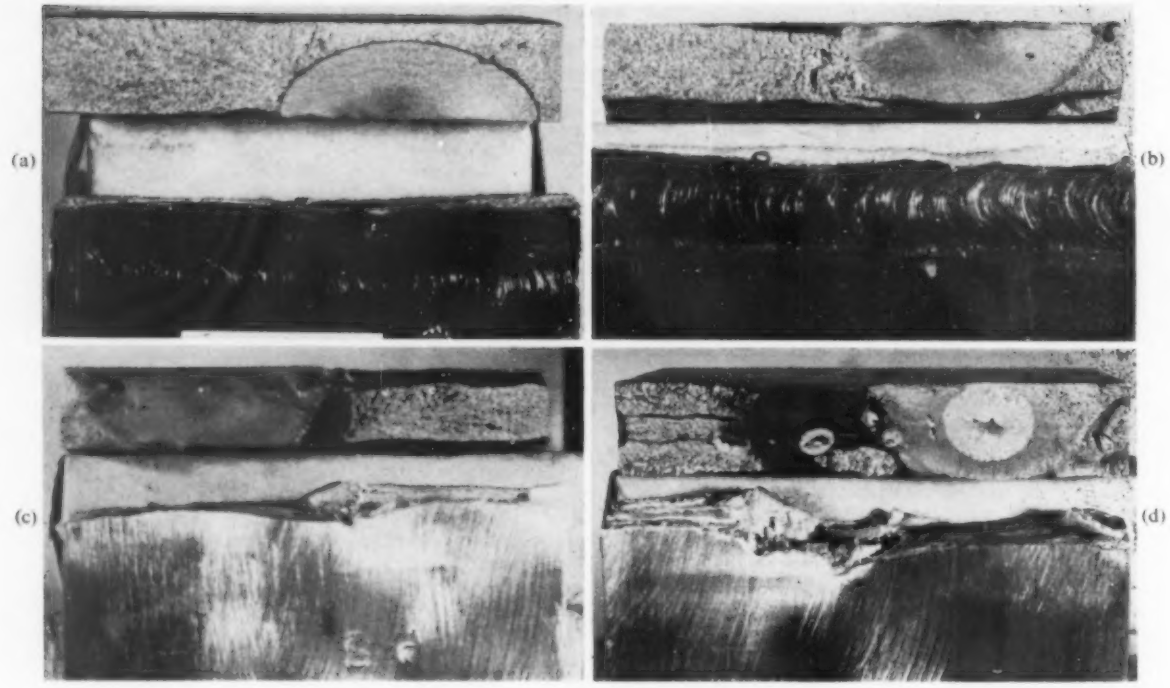
Preparation of joints

For sound transverse butt welds it is apparent, from an examination of failure locations, that the geometry of the weld reinforcement has an important effect on the fatigue behaviour. It is to be expected then that the removal of the weld reinforcement would result in an increase in fatigue strength. For much of the test data this is so; but the increase in the fatigue strength when the reinforcement is removed depends greatly on the quality of the weld.

Removal of the weld reinforcement removes one of the primary sources of initiation of fatigue failures but makes the internal defects much more significant. For high-strength steels, similar to those which are discussed in this paper, the presence of such internal defects will essentially eliminate any benefit that might be expected to result from removal of the reinforcement. The greatest increase in fatigue strength will be found for the case where the weld metal is free from all defects and the surface of the joint is ground in a direction parallel to the direction of stress; an improvement in the fatigue strength as much as 20% can be realized. However, if the weld metal contains internal flaws the fatigue resistance may be no greater, or possibly even less, than if the reinforcement had not been removed.



3—*Modified Goodman diagrams for transverse butt-welded joints:* (a) *Transverse double-V butt weld;* (b) *transverse single-V butt weld*



4—*Typical failures of transverse butt-welded joints*

Location of failures

Fatigue failures in transverse butt-welded connections generally occur in one of the following ways:

(i) At the edge of the weld reinforcement. Failures of this type are usually in the heat-affected zone and through the parent material. Such failures are greatly affected by the geometry of the reinforcement, and changes in the contour of this reinforcement or any undercutting can greatly affect the fatigue strength
(ii) At the line of fusion. Failures along this line usually result from incomplete penetration of the root pass. These failures can also result if the root pass is not properly cleaned on the back side before subsequent passes are deposited
(iii) In the weld metal. Failures of this type usually result from internal weld flaws, which may consist of porosity or slag inclusions.

Typical failures of butt-welded joints are shown in Fig. 4.

Longitudinal Butt-Welded Joints

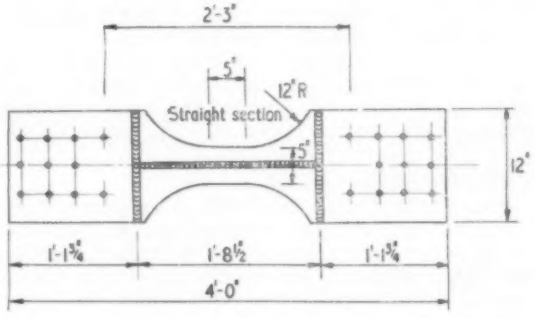
There is a limited number of test results available for longitudinal butt-welded joints. The general configuration of specimens for this type of test is shown in Fig. 5. As for the transverse butt-welded joints, the major variations between different investigations have been in the width of the test section and the thickness of the material. In general, the specimens have been prepared with a double-V butt weld running the entire length of the specimen.

Base metal

The tests carried out on specimens of this type have been conducted on ASTM A-242 and ST-52 low-alloy steels. If the strength of such joints is discussed in relation to the strength of similar joints in ordinary structural steel it is necessary to consider the difference in the electrodes used. For the low-alloy joints the electrode is generally of the low-hydrogen variety as well as one with a higher filler-metal strength. These two factors influence the results obtained. It can generally be expected that an increase of 4,000–5,000 lb./sq.in. in fatigue strength will result from the use of the higher strength low-alloy steels for longitudinally welded members.

Stress variations

Most of the tests on this type of specimen have been carried out on a zero-to-tension stress cycle. When compared with the transverse butt-welded joints the fatigue strength of longitudinal butt-welded joints at



5—*Typical test member with longitudinal butt weld*

10^5 cycles on a zero-to-tension stress is approximately 15% greater. At 2×10^6 cycles the longitudinal butt-welded member exhibits a strength approximately 20% greater than that of a member with a transverse butt-welded joint. This result is not unexpected when one considers the difference in the geometry of the joint. For the longitudinal joint the edge of the reinforcement is parallel to the direction of stress and does not, therefore, act as a serious stress raiser. Likewise, any lack of penetration of the root pass will result in a line that is parallel to the direction of stress.

For the case of complete reversal there are few tests available. On the basis of these test results, however, the fatigue strength in complete reversal is approximately 60% as great as that of joints tested on a zero-to-tension stress cycle. The total range of stress for reversal is then only slightly greater than that for a zero-to-tension cycle.

Preparation of joints

The most common treatments for longitudinal butt-welded joints are removal of the weld reinforcement and stress relief. Removal of the weld reinforcement increases the fatigue resistance. Polishing of the plate surface in a direction parallel to the direction of the stress may produce an additional increase. If, however, there are internal flaws, such as porosity or slag inclusions, the beneficial effect of removing the weld reinforcement may produce no change, or possibly a reduction, in the fatigue resistance. In such cases the removal of the weld reinforcement makes the inclusion the major stress concentration within the joint, and the fatigue crack will propagate from the inclusion.

Since the residual stresses in this type of joint are largest in the direction of the stress it would be expected that some sort of treatment to remove or reduce them should affect the fatigue strength. Much of the data on this point are not too clear. It would appear that little or no effect is produced by the residual stress if the joint is subjected to a stress cycle corresponding to a fatigue life of approximately 10^5 cycles. However, if the joint is subjected to stresses of a somewhat smaller magnitude, the increase in the fatigue strength for a life of 2×10^6 cycles is approximately 10%.

It is difficult to establish whether or not this effect is caused entirely by the removal of the residual stresses or by other changes which may take place, because any treatment that removes or reduces the residual stresses may also produce changes in the structure of the metal within the joint. The fact that the stress-relief treatment does not produce a significant effect at the shorter fatigue lives would lead one to believe that the stresses necessary to produce such short lives, even in the as-welded connection, are sufficient to reduce the residual stresses on the first few applications of the load.

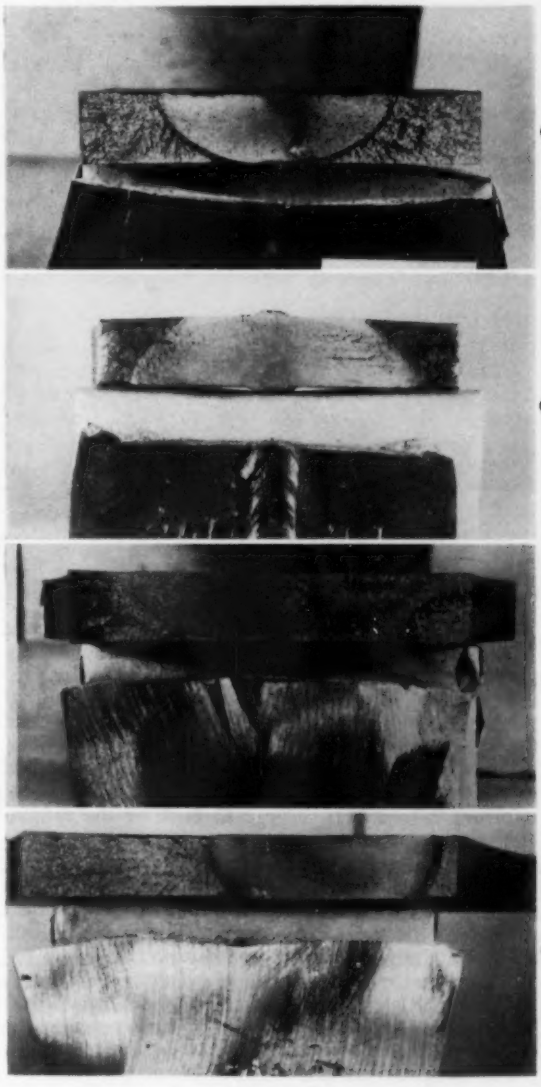
Location of failures

Fatigue failures in longitudinal butt-welded members usually initiate at the weld metal. Mostly, the cracks initiate either at internal flaws or at the ridges or ripples in the weld surface. When the weld reinforcement is removed the failures usually initiate at internal flaws, although even in this case failures may sometimes be found to initiate at the surface of the specimen in the weld metal. If the reinforcement is not removed, the location of failure is largely a question of which stress concentrator is the most severe. In any event the failure initiates at a point of stress concentration within the weld area.

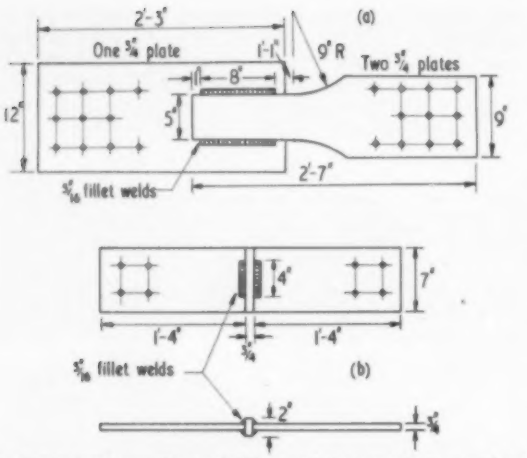
Table III

Typical fatigue strengths of longitudinal butt-welded joints
(Stress Cycle: Zero-to-Tension)

Steel	*Treatment*	$F_{100,000}$	$F_{2,000,000}$
A-242 (Steel P)[4]	As-Welded	44,700	30,300
A-242 (Steel P)[4]	Reinforcement removed	50,100	34,800
A-242 (Steel T)[5]	As-Welded	45,100	—
A-242 (Steel Q)[5]	As-Welded	42,200	—
Japanese (H.T.)[3]	As-Welded	59,800	34,200



6—Typical failures of longitudinal butt-welded joints



7—*Typical test member with fillet-welded joint*: (a) *Longitudinal fillet-welded joint*; (b) *tee-fillet-welded joint*

In the discussion of longitudinal butt-welded joints the role of the weld has been emphasized. It should be pointed out that the fatigue strengths for 2×10^6 cycles on a zero-to-tension stress cycle were all above 30,000 lb./sq.in. (13½ tons/sq.in.) and, when the weld reinforcement was removed, the fatigue strength closely approached the fatigue strength of the base metal. Typical fatigue strength values for this type of connection are given in Table III, and typical failures are shown in Fig. 6.

Fillet-Welded Joints

There have been several tests of fillet-welded joints in low-alloy steel conducted in Germany, Japan, and the United States. The general configuration of joints of this type is shown in Fig. 7. Both the longitudinal fillet-welded joint and the tee-fillet-welded joint have been studied. It is significant that for all the tests on connections of this form the results are extremely consistent.

Base metals

The base materials for tests of this type have strength properties which extend over only a very narrow range, from 75,000 to 90,000 lb/sq.in. (33½–40 tons/sq.in.). In some cases for longitudinal fillet-welded joints one end of the member had been fabricated from ordinary structural steel plate. The welding electrode used was governed by the properties of the low-alloy steel plate. This method of joint preparation caused very little difference in the fatigue strengths.

In tee-fillet-welded joints the failures occur through the throat of the weld metal. The strength of this type of joint is, therefore, dependent on the strength properties and area of the deposited weld metal. For all the data reported on tee joints, tested on a zero-to-tension stress cycle, the fatigue strengths at 10^5 and 2×10^6 cycles, respectively, are 22,000 and 12,000 lb/sq.in. (12 and 5½ tons/sq.in.). These stresses are calculated on the basis of the throat area of the weld.

For longitudinal fillet-welded joints the data reported are harder to interpret. In this type of connection there are several ways in which the geometry can be varied—the ratio of weld length to plate width; the ratio of the two plate widths—or a transverse weld can be added to the joint shown in Fig. 7*a* and the size of the weld itself can be varied. Since all these parameters have been used in the various investigations it is difficult to separate their individual effects. However, a good average value for the zero-to-tension fatigue strength at 10^5 cycles and 2×10^6 cycles would be 22,000 and 12,000 lb/sq.in. respectively. The variation from this value can be quite marked for some specific geometry.

Joint preparation

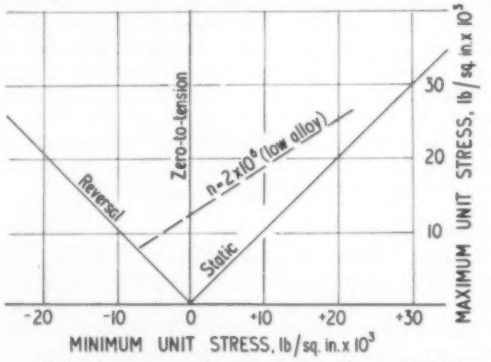
There is little that can be done to change the configuration of the deposited weld metal. For longitudinal fillet-welded joints it is virtually impossible to change the configuration of the weld metal deposited; the angle between the connected parts generally provides a 90 degree fillet weld, either by changing this angle before welding or by treating the deposited weld metal after welding. Because of the failure location it would seem that treatment of the weld surface would produce little or no change in the fracture location or the fatigue strength.

For tee-fillet-welded joints it appears that a relatively simple joint preparation can produce a significant effect on the fatigue strength. If the longitudinal plates are bevelled it is possible to provide complete penetration of the weld metal at the joint. This type of joint is sometimes referred to as a 'butt-fillet' joint because it does produce complete penetration. For this type of connection the fatigue strengths at 2×10^6 cycles is increased by 40% over the value that would be obtained for a conventional tee-fillet-welded joint.

One additional configuration has been investigated. For this, the longitudinal plate is continuous and a tee bar is attached by means of two fillet welds. This is, of course, not a joint but an attachment, and this is so short in the direction of stress that it cannot pick up any stress. As would be expected, the fatigue strength for this configuration is approximately twice that of the tee-fillet-welded joint at 2×10^6 cycles.

Stress variations

A sufficient number of tests of tee-fillet-welded joints has been carried out to construct a modified Goodman diagram for fatigue strength at 2×10^6 cycles. Such a diagram is shown in Fig. 8. In this figure



8—*Modified Goodman diagram for tee-fillet-welded joints*

"FASTEX 5"

-the best electrode for most jobs

The Murex "Fastex 5" electrode has many features which make it the best welding electrode for most jobs. It has exceptionally smooth running properties and general ease of operation in all welding positions. These are combined with low weld spatter and self-detaching slag. All these advantages ensure that high quality welds can be readily obtained for all general fabrication work, with neat and regular weld bead appearance and with freedom from undercut. Although primarily designed for flat and horizontal–vertical welding, the "Fastex 5" electrode can be used in all other positions and is acknowledged by experienced engineers throughout the world as the best general purpose electrode for welding mild steel.

MUREX

MUREX WELDING PROCESSES LTD., WALTHAM CROSS, HERTS

T37

FOR METAL-ARC WELDING OF HIGH NICKEL ALLOYS USE THE RIGHT ELECTRODE

For welding the high-nickel alloys special electrodes have been developed to give the best results. *Don't spoil good materials by using the wrong electrode.*

MATERIAL	METAL-ARC ELECTRODE	MATERIAL	METAL-ARC ELECTRODE
'A1' Nickel	'131' Nickel	INCOLOY* DS *heat-resisting alloy*	INCO WELD A
Low-Carbon 'A1' Nickel		NIMONIC* 75	NICREX* 4 or CHROMAC* N
DURANICKEL* *age-hardenable nickel alloy*		NIMONIC* 80A *heat-resisting alloys*	
MONEL* *corrosion-resisting alloy*	'130' MONEL	NIMONIC* 90	
'K' MONEL* *age-hardenable corrosion-resisting alloy*	'134' K MONEL	BRIGHTRAY *B	NICREX* 3
NI-O-NEL* *corrosion-resisting alloy*	'135' NI-O-NEL	BRIGHTRAY *C	NICREX* 4 or CHROMAC* N
CORRONEL* 210 / CORRONEL* 210 *corrosion-resisting alloy*	CORRONEX* B	BRIGHTRAY *F *high-temperature electrical resistance alloys*	INCO-WELD* A
INCONEL* *oxidation-resisting alloy*	'132' INCONEL	BRIGHTRAY *H	NICREX* 4 or CHROMAC* N
INCOLOY* *heat-resisting alloy*	INCO-WELD 'A'	BRIGHTRAY *S	NICREX* 4 or CHROMAC* N

**Trade mark*

SEND FOR THIS BOOKLET

Full details of welding techniques by all processes are given in our welding handbook, '*Welding, Brazing and Soldering of Wiggin Nickel Alloys*'. Write for your copy.

NAME _____

COMPANY _____

ADDRESS _____

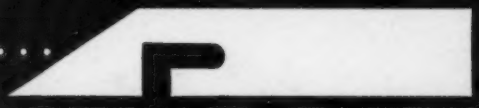
BW/M29/4

We have available a 16-mm sound film in colour entitled '*Welding of Wiggin High-Nickel Alloys*' which is available without charge for showing to engineering societies, training classes, etc.

HENRY WIGGIN & COMPANY LIMITED • WIGGIN STREET • BIRMINGHAM 16

TGA M29A/1

What is
the cheapest
and simplest way
of fixing
this . . .



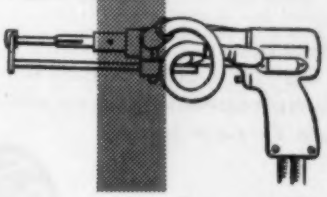
to this? . . .

When both are metal—the answer is almost invariably stud welding. The cost may be as little as one fifth of, for instance, the cost of drilling and tapping. The time an even smaller fraction. And stud welding is far stronger than any alternative method and absolutely permanent.

Stud welding is speeding up production and lowering costs in an immense range of industries from shipbuilding to domestic equipment. Attachments may be of almost any shape. A talk with our Engineers perhaps, followed by a demonstration, will be worth your while.

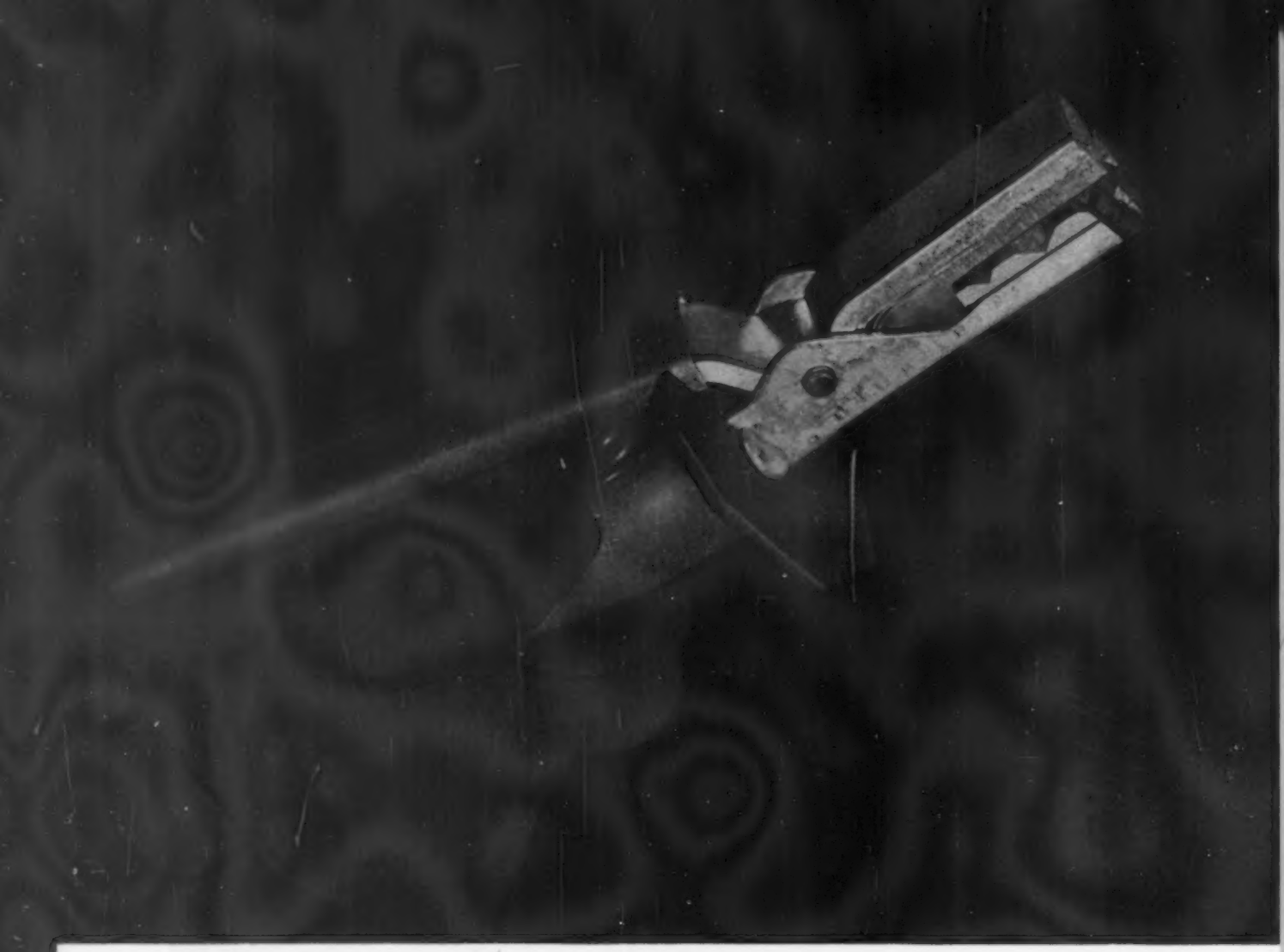
Crompton Parkinson

STUD WELDING



ELECTRICAL EQUIPMENT

CROMPTON PARKINSON (STUD WELDING) LIMITED
1-3 Brixton Road, London, S.W.9. Telephone: Reliance 7676

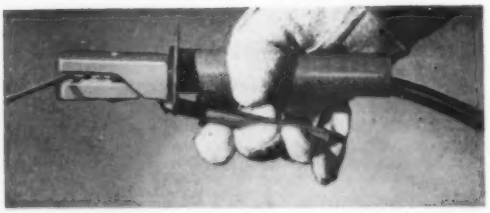


Better welding–
with the new Quasi-Arc 'HANDICOOL 600'

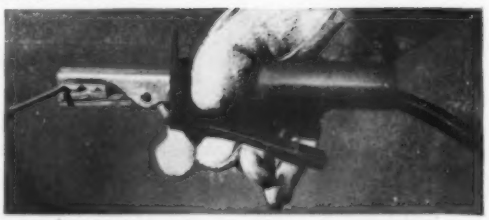
A new design of 600 amp. electrode holder with built-in welder appeal.

* *Better access* with the new close-angled lever shape.
* *D-section insulation* on handle and lever gives a compact grip.
* *Comfortable balance* and *cool welding* minimise fatigue.
* *Full insulation*—tested at 2,000 volts — on the Handicool 600 (insulated) model.
* *All parts are renewable* when worn.
* Tough copper wear-resisting jaws with deep-groove slots, flexible copper conductor strips, cadmium-plated body to resist rust and spatter, fully shielded and insulated spring—all these features add up to the latest and best electrode holders for cool, comfortable, safe welding.

And the price is right—
Handicool 600—28/6d. each. Handicool 600 (insulated)—32/6d. each.
(Special discounts for quantities of 1 dozen or more)
Write for leaflet T.C.124 for full details



Handicool 600 (insulated)



Handicool 600

Quasi-Arc **world leaders in arc welding**

A BOC Company

Quasi-Arc Limited, Bilston, Staffordshire. Tel: Bilston 41191

the stresses have been calculated on the throat area of the welds.

Location of failures

For the tee-fillet-welded joints the failures always occur across the throat of the fillet weld. Typical failures of this type are shown in Fig. 9. For the longitudinal fillet-welded joints the failure usually takes place in one of the outside plates. The fatigue failure initiates at the end of the fillet weld in the parent plate since this is a point of high stress concentration. It makes no difference whether this terminal of the fillet weld is the strike end or the crater end of the electrode deposit.

Conclusions

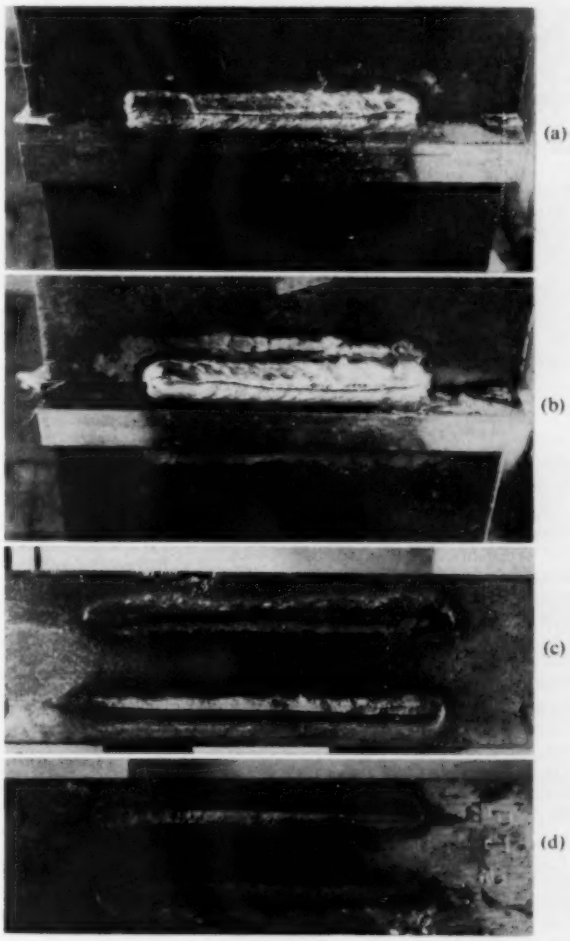
On the basis of the discussion contained in this paper and on the test results that were used as its basis, it can be stated that, in general, the fatigue strength on a zero-to-tension stress cycle of transverse butt-welded joints in low-alloy structural steels does not differ significantly from the strength of the same type of joint in ordinary mild grade structural steel when the comparison is made at 2×10^6 cycles. This is particularly true if the joint in the ordinary structural steel is made with a low-hydrogen electrode. The particular advantage of the low-alloy steels would appear to occur when the stress cycle covers a small range from some value of tension stress to a maximum tensile stress. In this case it is possible to use a greater value of the maximum stress for the low-alloy steels than for the ordinary structural steels.

The improvement of fatigue life of transverse butt-welded joints obtained by treatment of the weld, such as removal of the weld reinforcement or grinding of the plate surface at the joints, is dependent on the internal structure of the weld. If there are significant weld defects within the weld metal there may be no improvement as a result of such treatment.

For the longitudinal butt-welded joints there is an improvement in fatigue strength over ordinary structural steel if a low-alloy steel is used. This is to be expected, since the fatigue properties of this type of joint are largely a function of the base-metal properties. In almost all cases the fatigue strength of this type of connection approaches very nearly that of the parent-plate. As for the transverse butt-welded joints, any improvement expected from the removal of the weld reinforcement is dependent on the internal structure of the weld.

It is apparent, on the basis of the test results and from the discussion, that to obtain maximum improvement over ordinary structural steel it is necessary to control the weld defects to a much greater degree in the high-strength steels than is necessary in ordinary structural steels. It is basically for this reason that the average of the test results available indicates that there is relatively little advantage in using high-strength steels where a large number of repetitions of stress is expected.

The maximum values for fatigue strengths of butt-welded joints do indicate that it is possible to obtain strengths much greater than those obtained for ordinary structural steel. However, to obtain such values consistently and intentionally it will be necessary to have a much better understanding of how a nearly perfect weld can be assured, and just how the internal flaws influence the fatigue properties of the welded joint.

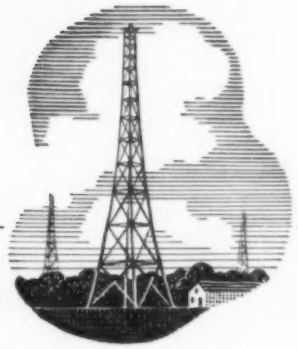


9—*Typical failures of tee-fillet-welded joints*

SELECTED BIBLIOGRAPHY

1. Von K. KLOPPEL and H. WEIHERMULLER: *Stahlbau*, 1957, No. 6, pp. 149–155.
2. S. WINTERGERST and E. RUCKERL: *Stahlbau*, 1957, No. 5, pp. 121–124.
3. I. KONISHI, O. TAKAGI and K. SHIMADA: *Proc. Japan Soc. Testing Materials*, 1958, pp. 10–14.
4. G. E. NORDMARK, J. E. STALLMEYER and W. H. MUNSE: "Fatigue and Static Properties of Welded Joints in Low Alloy Structural Steels", SRS No. 90, University of Illinois, Department of Civil Engineering, January 1955.
5. G. E. NORDMARK, Z. SHOUKRY and J. E. STALLMEYER: "Fatigue and Static Properties of Welded Joints in Low Alloy Structural Steels, II", SRS No. 114, University of Illinois, Department of Civil Engineering, January 1956.
6. R. K. SAHGAL and J. E. STALLMEYER: "Fatigue and Static Properties of Welded Joints in High Strength Structural Steels", SRS No. 172, University of Illinois, Department of Civil Engineering, April 1959.
7. W. H. MUNSE: "Fatigue of Welded Steel Connections", University of Illinois, Department of Civil Engineering. (In preparation)

NEWS
and Announcements



News of the Institute and Branches
B.W.R.A. · Other Societies ·
and Industry

INSTITUTE ACTIVITIES

Council Nominations

At its meeting on 3rd March the Council unanimously agreed to the following nominations for the Council Elections of 1960.

President
Mr. E. Fuchs

Vice-President Mr. H. West

Hon. Treasurer Mr. W. E. Harriss

To represent Industrial Corporate Members
Mr. E. V. Beatson
Mr. C. Humphrey Davy
Mr. J. A. McWilliam
Mr. C. L. Railton

To represent Fellows, Members, and Associate Members
Mr. G. M. Boyd
Mr. F. Clark, M.B.E.
Mr. J. A. Dorrat
Mr. E. Flintham
Mr. R. J. Fowler
Dr. N. Gross
Mr. E. J. Heeley
Mr. R. M. Watts

To represent Companions
Mr. J. Hooper

To represent Associates
Mr. A. Evitts

Membership of Council

Dr. M. C. Nickson has resigned his seat on the Council as representative of the South London Branch, the Committee of which has appointed its present chairman, Mr. P. J. E. Heath, to succeed him for the remainder of his term of office.

Past President's Gift

Before the Council meeting on 3rd March, Mr. John Strong, immediate Past President, presented to his successor in the chair (Mr. E. Seymour-Semper), an electric sunray clock to commemorate his presidency in the year 1958–59.

The President, on behalf of the Institute and supported by members of the Council present, expressed gratitude for the gift, which notably improves the furnishing of the Council Room.

Larke Medal Award

On the recommendation of the examiners the Council of the Institute has awarded the Sir William J. Larke Medal for 1959 to C. A. Terry and E. A. Taylor for their paper "*Welding of Cupro-Nickel and Aluminium-Bronze Alloys*" (B.W.J., May 1958, p. 211).

The following two papers were highly commended: "*High Current Inert-Gas Metal-Arc Welding of Aluminium*" by A. A. Smith and P. T. Houldcroft (B.W.J., September 1958, p. 421); and "*Manual 'Open Air' Welding of Reactive Metals*" by J. C. Borland and W. G. Hull (*Ibid.*, p. 427).

Educational Policy

Early in January the President established a Presidential Committee on Educational Policy which made its first report to the Council at the beginning of March. A number of Technical Colleges and Universities have approached the Institute with offers of advanced courses in welding technology suitable for the education of a professional specialist in welding and it looks as though this country will shortly be free of the reproach that alone among the leading industrial nations it makes no provision for welding instruction at this level.

It is intended shortly to convene a one-day conference of leading educationists and industrialists to consider what are the needs of industry in respect of welding specialists and how best those needs can be met.

Welding Mission to the U.S.S.R.

The Institute of Welding has approached the Soviet authorities with proposals for a mission of welding specialists to visit Russian research laboratories, technical universities and works employing welding. The arrangement would be made under the Anglo-Soviet Protocol and would involve a return visit by Russian specialists.

MEETINGS

Spring Meeting 1960 (Droitwich)

The Spring Meeting of the Institute will be held at Droitwich from **9th–11th May, 1960,** and will be devoted to the novel welding processes and metal spraying. The programme includes an opening reception at the Worcestershire Brine Baths Hotel in the early evening of Monday, 9th May, two morning sessions, on Tuesday and Wednesday, and one afternoon, for the discussion of technical papers, a choice of works visits on the Tuesday afternoon, and a concluding dinner on the Wednesday evening.

The Conference centre will be the Winter Gardens, Droitwich, and most of the supply manufacturers will be taking part in a display, illustrating new welding processes and varied applications of metal spraying.

Four papers on different aspects of metal spraying will be presented and discussed at the first technical session.

An adjustment has had to be made in the programme as previously announced. Instead of demonstrations on the afternoon of Wednesday, 11th May, three papers on Slag Welding, which were to have been included with three others on different subjects in the morning's discussion, will be presented and discussed at the Winter Gardens.

The Institute's First Lecture to Young People

On 5th January the Institute's first lecture to young people was given by Professor Hugh O'Neill, M.Met., D.Sc., F.I.M. It was entitled '*The Magic Arc*'

Professor O'Neill presenting the first Institute Lecture to Young People

and was attended by about one hundred young people from secondary modern and grammar schools, and from industry.

The lecture traced the scientific background to the modern uses of the electric arc, with particular reference to welding, and described the arc welding processes which are now available to industry. The lecture was illustrated with slides and demonstrations, which included a novel demonstration in which the welding arc was projected onto a screen at a magnification of eighty times.

Welding and the Design of Ships

A large and distinguished audience gathered at the Institute on the evening of 3rd March to hear the Third Annual Lecture on Welding and the Design of Ships by Mr. W. G. John, R.C.N.C., M.R.I.N.A., Deputy Director of Naval Construction. The Chair was taken by the President, Mr. E. Seymour-Semper, who also moved the vote of thanks which was most heartily accorded to the lecturer.

The text of Mr. John's lecture will be published in a later issue of the *British Welding Journal*.

After the meeting, Mr. John and the President were the guests of the Council at dinner at the Gore Hotel, Queens Gate, where the entertainment took the form of an Elizabethan Feast, the menu including such unfamiliar items as boar's head, sturgeon, and lamb in coffin, while a minstrel provided a musical background for a very enjoyable evening.

PUBLICATIONS

Year book

The Council of the Institute has entered into a contract with John Morris Publicity Limited, who publish year books or printed lists of members for the Institution of Civil Engineers and a number of other institutions, to print and publish an Institute of Welding Year Book, which would include a complete list of members. No printed list has been available since the earliest days of the Institute.

"The Electric Arc in Welding"

The papers presented at the Joining of Metals Conference organized by the Department of Industrial Metallurgy at the University of Birmingham last June, which were published in the February issue of the *British Welding Journal*, are now available as a separate reprint, price 7*s*. 6*d*., and may be obtained from the Secretary of the Institute.

APPEAL TO INDUSTRY

The following list records subscriptions received since the publication of the list in July 1959.

Donations

£100 each	Imperial Chemical Industries Ltd., International Combustion (Holdings) Ltd., Joseph Lucas Ltd., Shell-Mex and B.P. Ltd., John Thompson Ltd.
£52 10*s*.	Atomic Power Constructions Ltd.
£25 each	English Steel Corporation Ltd., Redheugh Iron and Steel Co. (1936) Ltd., Richardsons Westgarth Ltd.
£20	Deloro Stellite Ltd.
£12 12*s*. and less	The British Steel Piling Co. Ltd., Plowright Brothers Ltd.

Subscription

£10 p.a.	Westinghouse Brake and Signal Co. Ltd.

The total sum given or promised to date is £10,463 12*s*.

ELECTION OF MEMBERS

The following elections were made at the Council meeting of 19th November, 1959:

Hon. Member

***J. G. Williams** (Porthcawl).

Members

S. Astley (Wolverhampton); **Prof. J. G. Ball** (London); §**R. H. Boughton** (Liverpool); **D. N. Brittain** (Wolverhampton); **G. A. Curson** (Addlestone, Surrey); **E. J. L. Howard** (Wilmslow, Ches.); **L. Jones** (Cheltenham); **H. B. Merriman** (New Malden); **D. R. Milner** (Birmingham); **V. C. Pitick** (Worcester Park); **P. K. Richards** (Tettenhall, Staffs.); **W. F. Smith** (Croydon); **H. Vinter** (Copenhagen).

Associate Members

J. C. Adams (Littleover, Derby); **C. R. Allum** (London); **R. F. Atkinson** (Poynton, Ches.); **A. H. Bardell** (Doncaster); **Y. P. S. Bishnoi** (India); †**C. B. Brown** (Nottingham); **D. A. Bunney** (London); †**G. D. Carline** (East Grinstead); **D. P. Chatterjee** (India); **B. D. Cheal** (Worthing); **F. R. Denson** (Bolton); **A. M. Ellingford** (Ilford); **H. Entwistle** (London); **T. S. Eyre** (Slough, Bucks.); **V. Fetsch** (London); **F. B. Fuller** (Hull); †**M. E. Garland** (Hull); ‡**L. Gibson** (Stockton-on-Tees); **G. A. Hitchcock** (Belvedere, Kent); **F. C. Inskip** (North Ferriby, E. Yorks.); **P. Keen** (Southampton); **J. W. Lambert** (Sheffield); **A. Levi** (London); **H. J. G. Mercer** (Wolverhampton); ‡**F. Moody** (Connah's Quay, Chester); **J. Myers** (Rotherham); **G. Newcombe** (Plymouth); **A. W. Spackman** (North Harrow); **J. Stuart** (Erith, Kent); **D. W. Taylor** (Weybridge); **S. Whittingham** (Manchester); **K. Wileman** (Derby); **R. Wood** (North Shields).

Companions

G. A. Abbruzze (London); **K. Harper** (Solihull, Warwicks.);

A. E. G. Morgan (Cardiff); **J. Paton** (Rock Ferry, Ches.); **S. E. Robins-Cherry** (Northampton); **H. V. Roman** (Macclesfield) **T. Saville** (Ipswich).

Graduates

J. M. A. Blatchford (Midsomer Norton, Bath); **J. A. Davies** (Ossett, Yorks.); **R. W. Gant** (Cambridge); **W. H. Johnson** (Birmingham); **R. T. Towers** (Romford).

Associates

M. Amadi (Nigeria); **P. G. Barrett** (Banbury, Oxon); **J. A. Blakeborough** (Darlington); **L. G. A. Clark** (Rode, Bath); **H. S. Conner** (Hartford, Ches.); **W. Cooke** (Bridgewater); **H. A. Curtis** (Swindon); **F. Davies** (Oldham, Lancs.); **H. Franks** (Acomb, Yorks.); **D. Gasson** (Bristol); **H. J. Gee** (Atherstone, Warwicks.); **A. W. J. Gutteridge** (Ashford, Kent); **W. Hudman** (Swansea); **R. H. Hyatt** (Enfield); **K. Leake** (Leigh, Lancs.); **J. A. Masters** (Southport, Lancs.); **L. Minehan** (Manchester); **K. L. Nixon** (Southampton); **E. O. Oshin** (Nigeria); **D. L. Robinson** (London); **E. C. Rogers** (Redcar, Yorks.); **E. Rothwell** (Heywood, Lancs.); **H. G. Thorogood** (Wrexham, Denbigh); **J. Tomlinson** (Billingham-on-Tees); **G. S. Upfield** (Petersfield); **R. A. Webster** (Southampton); **W. H. Welch** (Stapleford); **K. Wood** (Nottingham); **D. A. Youngs** (Bishopstoke, Hants.)

Industrial Corporate Members

Blackburn (Dumbarton) Ltd.; W. E. James & Sons (Precision Engineers) Ltd. (Leatherhead); **Metal and Pipeline Endurance Ltd.** (Woolmer Green, Herts.); **Yorkshire Electricity Board** (Scarcroft, Leeds).

* Transfer from Member † Transfer from Graduate ‡ Transfer from Associate §Transfer from Associate Member

NEWS OF MEMBERS

Mr. **J. M. Willey, M.Inst.W.,** Director and General Manager of Murex Welding Processes Ltd., has recently been appointed to the board of Murex Ltd., Rainham.

Mr. **C. Phillips,** formerly of John Thompson Ltd., recently took up an appointment as Welding Engineer, with Morfax Ltd., Mitcham.

Mr. **K. H. Ewen, A.M.I.Mech.E.,** Chairman of the East Midlands Branch, has been promoted to Works Manager at the Derby works of Aitons Ltd.

CONTRIBUTORS TO THE JOURNAL

J. F. Alder, M.A., Ph.D., is a Senior Scientific Officer at the Military Engineering Experimental Establishment at Christchurch. He was educated at Rendcomb College and at Emmanuel College, Cambridge. After taking the Mechanical Sciences Tripos, he stayed on at Cambridge for three years in the Cavendish Laboratory investigating the effects of the speed and temperature of testing on the compressive strength of various metals, as part of the experimental rolling mill programme of the British Iron and Steel Research Association.

Since joining M.E.X.E. in 1951 he has been concerned with the design, development and testing of equipment used by the Royal Engineers.

William Edward Ballard, F.R.I.C., F.I.M., A.I.Mech.E., M.Inst.W., was born in 1896 in Birmingham, and was educated at the Birmingham Municipal Technical College. He started his career at the Muntz Metal Company as a chemist, in 1913, but this was interrupted by military service during the First World War. Since 1923 he has been Managing Director of Metallisation Ltd., and is a director of several other companies.

In 1949, Mr. Ballard was elected Vice-President of the Institution of Metallurgists and became President in 1958. He has also been President of the Birmingham Metallurgical Society.

In 1955–1956, he was President of the Dudley Rotary Club, and is at present the President of the Dudley Chamber of Commerce.

He is a member of the Institute of Welding Technical Committee, and is a British representative on the Sub-Commission of the International Institute of Welding dealing with Metal Spraying

H. F. a'Brassard, Director of Elm Engineering Ltd., was educated at Cambridge. He was called up as a Territorial at the outbreak of war in 1939 and served in the Royal Artillery where he became a Staff Officer G.S.O.II.

Following demobilisation he joined Tube Investments Ltd. and remained in the tube manufacturing division until December 1958, spending time with such firms as Accles & Pollock, Talbot Stead, Tube Products and latterly T.I. Aluminium, who eventually became Reynolds T.I. Aluminium.

Since January 1959, he has been in charge of Elm Engineering Ltd., the tube manufacturing division of the Antiference Group Ltd., which produces television aerials and tubular chairs.

C. J. Cooksey was educated at Bromsgrove School, Worcs., and at the University of Birmingham where he graduated with a B.Sc.(Hons.) in Industrial Metallurgy in July 1958.

He is at present engaged in research work at the University where he is a member of the "Joining of Metals" team, investigating problems associated with vacuum arc melting.

L. F. Defize a chemist with N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands, studied physical chemistry at the Technical University of Delft, graduating in chemical engineering in 1950. He joined the Welding Department of the Physical Laboratory of

Dr. J. F. Alder

H. F. a'Brassard

C. J. Cooksey

L. F. Defize

New AEI Single-Operator A.C. Arc Welding Sets

The latest 'Thermac' a.c. hand-welding sets incorporate improved design features which provide greater mobility and ease of operation. They require practically no maintenance. Both models comply with B.S. 638/1954.

ALTERNATIVE RATINGS
Model 185799 has a continuous hand welding current range of 50-250 amps, with a maximum intermittent current of 333 amps.
The larger set, model 185800, has a current range of 75-350 amps, with a maximum intermittent current of 450 amps.

SMOOTH CONTROL
The moving-coil regulator gives infinitely variable adjustment of welding current over the whole range without the use of tappings.

SAFETY
Sets are air cooled, making fire risk negligible.

EASE OF ACCESS
All working parts are easily accessible.

Please write for descriptive leaflet 783/17-1 to your local AEI office or direct to–

AEI

Associated Electrical Industries Limited

TRANSFORMER DIVISION - Heating & Welding Department

TRAFFORD PARK, MANCHESTER 17

FOLDING

FLANGING

EDGE CURVING

CORRUGATING

AND

VARIOUS OTHER

OPERATIONS

OF THE

STEEL FABRICATOR

are carried out rapidly
and efficiently by

HUGH SMITH

FLANGING PRESSES

These self-contained electro-hydraulic presses have smooth, accurately controlled action which ensures exact working, with full power at any point of the stroke. They are very robustly built and especially well guided, with hydraulic rams acting directly on the moving beam. A special hydraulic balancing valve is fitted to ensure parallel motion of the beam independent of the guides.

3 MODELS: 300 TONS · 450 TONS · 600 TONS

Hugh Smith Machines include

Plate-edge Planers, Plate Bending Rolls, Plate Straightening Rolls, Cold Frame Benders, Gap Presses, etc.

HUGH SMITH & CO. (POSSIL) LTD., HAMILTONHILL ROAD, GLASGOW, N.2

Dr. W. Gilde

E. M. Lewis

Professor W. H. Munse

A. Neumann

Philips' Research Laboratories, Eindhoven, and worked with Dr. van der Willigen on gas-metal reactions in arc welding, paying special attention to theoretical problems connected with the development of automatic welding processes and also on the physics of the welding arc.

Mr. Defize is the author of several papers on drop transfer and on automatic welding. He is a member of the Dutch Chemical Society and of the Dutch Welding Society.

Dr.rer.nat. **Werner Gilde** is Director of the Central Institute of Welding of the German Democratic Republic, Halle/Saale. He is working on questions of the metallurgy and automatization of welding processes.

The work described in his paper (*B.W.J.*, March 1960, p. 208) was carried out during investigations on surface tension of metals and its influence on their strength.

E. M. Lewis was educated at Ardwyn Grammar School and at the Imperial College of Science and Technology. During the war he served in the Technical Engineering Branch of the R.A.F.V.R. and joined W. S. Atkins & Partners in 1946, where he is now Director of Research.

W. H. Munse, Professor of Civil Engineering at the University of Illinois, Urbana, Illinois, U.S.A., graduated from the University of Illinois with a M.S. degree in 1944. His professional experience includes work as assistant to the City Engineer of Champaign, Illinois; engineer with the American Bridge Company; naval officer in the Civil Engineering Corps U.S. Navy; research engineer at Lehigh University; and member of the research and teaching staff at the University of Illinois. In the latter position, over a 15 year period, his work has encompassed a variety of subjects in the structural field, including many studies of the behaviour of concrete, steel, and steel structures, and at present includes the responsibility for the general direction of the department's extensive research programme on metals and metal structures. However, much of his research has been in the field of fatigue in steel and in riveted, welded, and bolted structures. Mr. Munse is a member of many engineering societies and their technical committees; these include the American Society of Civil Engineers, American Welding Society, American Society for Testing Materials, American Society for Engineering Education, American Railway Engineering Association, and American Concrete Institute.

Dipl.-Ing. **Alexis Neumann** is Head of the Research Department of the Central Institute of Welding of the German Democratic Republic, Halle/Saale.

At present he is working on the design of welded constructions with particular regard to their fatigue strength.

J. E. Stallmeyer is Associate Professor of Civil Engineering at the University of Illinois, Urbana, Illinois, where he received his Ph.D. in 1953. Since 1947 he has been associated with the Structural Research Group of that Department, and has carried out work in the basic mechanisms of fatigue and cumulative damage. Since 1955 he has been directly associated with work on fatigue of welds in low-alloy structural steels, behaviour of built-up beams subjected to repeated flexural stresses, and preparation of a summary of fatigue data on welded joints.

Mr. Stallmeyer has attended the I.I.W. as an expert on Commission XIII, Fatigue Testing, and is currently on Commission XIV, Welding Instruction.

J. G. Whitman, M.Eng., Ph.D., A.M.I.C.E., M.Inst.W., is a Senior Principal Scientific Officer at the Military Engineering Experimental Establishment, Christchurch, where he is the Head of the Research Group.

He was educated at the King Edward VII School, Sheffield, and graduated with honours from Sheffield University. After four years post-graduate research into structural fatigue problems he was appointed to the Iron Works Department of Newton, Chambers & Co. Ltd., and from there moved on to his present Establishment. His duties here were, for some years, concerned with the design and development of R.E. equipment, but he is now in charge of the Section responsible for the Research work of the Establishment.

J. L. Wood, B.Sc. (Eng.), a mechanical engineer in the Mechanical and Structural Research Group of the British Aluminium Co. Ltd., graduated in mechanical engineering at London University in 1951. From 1951 to 1952 he gained workshop experience with the Norwood Engineering Company (now known as the Norwood Instrument Company), and in the following four years he gained wide experience of the design and manufacture of flow control

The papers of some of these contributors were published in the February and March issues of the Journal

Dr. J. G. Whitman

J. L. Wood

valves at J. Blakeborough and Sons Ltd., Brighouse, Yorks.

Mr. Wood joined the British Aluminium Company in 1956 in the capacity of mechanical engineer and his responsibilities cover stress analysis, applications development, and fatigue investigations. He was elected to represent the South Buckinghamshire and Oxfordshire areas on the Eastern Branch Committee of the Institution of Mechanical Engineers' Graduate Section in 1959.

BRANCH NEWS

Joint London Branches Dinner

In 1959 the Annual Dinner of the North and South London Branches of the Institute was held during the Spring Meeting of the Institute and this added to the already large anticipated attendance of members and visitors.

However, the Dinner is fast becoming one of the most popular events in the welding field, and the Organizing Committee has therefore decided that the 1960 Dinner should be held in the Grand Hall of the Connaught Rooms. This can accommodate over 400 persons and will allow greater freedom in the choice of individual tables to seat parties of 8 or more people.

As in other years a room (this time the Balmoral Suite) will be available before and after the Dinner, so that members may meet each other informally. Space will be far less cramped than before.

One feature of this Joint Annual Dinner is that speeches are kept brief so as to allow the maximum time for this informal discussion; but it is understood that the Committee are hoping to be able to invite some interesting personalities as guests.

Members of the London Branches, and particularly those from other Branches, are heartily invited to attend this year's function, which will be held on Thursday, 21st April, 1960. Tickets (price 32*s*. 6*d*.) may be obtained from P. J. E. Heath, Esq., 33 Grosvenor Place, London, S.W.1.

East Midlands

A meeting of the Branch was held on Wednesday, 20th January, at the College, Loughborough, when a paper based on "*The Welding Fabrication connected with the British Transport Comission Diesel Development Programme*" was presented by Mr. G. Walton—a member of the Branch.

The paper related to the use of welding as a production tool in the manufacture of rolling stock, and it outlined the standard procedures of materials, electrodes, joint preparation, and control of metal deposition, which are carefully assessed and controlled, owing to their marked influence on welded structures.

The extensive use to which jigs and fixtures are employed was amply illustrated, the deciding factors influencing their use being:

(*a*) The control of distortion
(*b*) Ease of welding due to accessibility
(*c*) Reduction in handling time
(*d*) Enhanced overall productivity rates

The lecturer then went on to describe the construction of the principle details of diesel locomotives, types Bo-Bo and Co-Co at present being manufactured in both Crewe and Derby Locomotive Works.

It was clearly illustrated by means of slides the accuracy which can be obtained when constructing a 63 ft long diesel underframe. This has been possible as a result of co-ordination between the Design Office, Planning Office and Works. A limit of $\pm\frac{1}{16}$ in. in overall length was achieved in production.

The method of attaching the side skins to the superstructure to obtain a stable construction when the power equipment is added was explained, and the paper covered the construction of the standard design of an all-steel B.R. passenger coach. Slides clearly showed the extensive use of jigs, fixtures and registration equipment for accuracy of assembly to aid mass production.

Similar illustrations were used to describe the construction of 16-ton mineral wagons employing an all-welded body. Emphasis was laid on procedure control, welding standards, the methods of testing welders, and the assessment of the test welds. Testing was intended, primarily, to offer to operators an opportunity of examining their work critically, and, through discussion with the inspectors, to improve or maintain the standard of weld quality.

A stimulating discussion followed, which was felt to be a measure of the subject's interest to the members present.

G.W.

Manchester

For the fifth meeting of the Branch held on 6th January at the Manchester College of Science and Technology, members and visitors heard a paper entitled "*Inspection and Interpretation of Welding Codes*" by C. Atkinson, A.M.C.T.

The lecturer mentioned the multitude of codes which now exist relating to welding and emphasized the danger of just extracting and using such bits that would appear to satisfy a particular requirement. Visual inspection, with its many faults, had, as a result, led in certain quarters to deep-rooted objection to welding. What was the object of inspection? In Mr. Atkinson's view, it was to see if a weld was good enough for its job. For this, certain essentials had to be observed, among which were right material, correct preparation, root gap uniformity, and correct alignment. Welding procedure and welders' qualifications were equally important, and on the latter point Mr. Atkinson emphasized the need for welders to qualify under service conditions. Furthermore, the results of weld tests should be shown to welders as a means of obviating future failures.

Other points which had a bearing on the theme were put forward, such as preheating, post-welding inspection, post-heat treatment, correct electrode storage, adequate and efficient supervision on the actual job itself. Mr. Atkinson said that the formulation of a code to cover all allowable defects for welds in service was extremely difficult.

The lecturer illustrated his many points with slides, and very ably answered the questions put to him during the discussion time.

A.C.W.

North London

An excellent paper was presented by Mr. A. Prince at the meeting on Wednesday, 20th January, when he chose as his subject "*Further Developments in the Welding of Atomic Plant*". Very good support was given to this lecture, covering fabrication works at Hunterston, which was illustrated by slides. Types of steel used, and the various forged fittings of both British and European origin, were discussed. The electro-slag method was covered and the points regarding all-positional welding, on such things as spheres, were mentioned. Accent was laid on the stress relief of weldments at site, and the change in results where different temperatures in the range 550–650°C. were used. Mr. Prince emphasized the need for a standard covering atomic power work.

In the interesting question time which followed the lecturer proved to be a master of his subject, and dealt most ably with the controversial points raised. Many important companies, interested in this field, were represented in the large number of engineers present.

R.B.W.

Sheffield

Annual Dinner

The Branch held its thirteenth Annual Dinner at the Royal Victoria Hotel on Monday, 4th January. Nearly 200 members and guests attended, and Mr. A. Robert Jenkins, J.P., the Branch President, was in the chair.

The toast of the Institute of Welding and the Branch was proposed by the

The Branch Chairman, S. B. Rippon, J.P., the Institute President, E. Seymour-Semper, and the Branch President, A. Robert Jenkins, J.P. at the Sheffield and District Annual Dinner

Master Cutler, Mr. P. J. C. Bovill, J.P. In his response the President of the Institute, Mr. E. Seymour-Semper, appealed for the energetic support of all members of the Institute in ensuring adequate advanced instruction for welding specialists, for whom the universities and technical colleges at present make no provision.

The toast of the guests was proposed by Mr. S. B. Rippon, J.P., the Branch Chairman, and the response was made by the Lord Mayor of Sheffield, Alderman A. V. Wolstenholme.

High Vacuum

The Annual Joint Meeting between the Branch and the Rotherham Engineering Society was held on 11th January in the Assembly Hall at the Rotherham Technical College. Mr. S. B. Rippon, J.P. (Branch Chairman) took the Chair.

"*High Vacuum, its Production and Use*" was very clearly explained by Mr. L. G. Beckett of E. Edwards High Vacuum Ltd. Slides, a film, and a most impressive array of equipment were used as visual aids and for practical demonstrations.

The meeting was attended by 86 members and visitors and Mr. Beckett ably dealt with questions from the audience to conclude a most interesting and educating evening.

Wolverhampton

Mr. H. B. Merriman presented his paper entitled "*Welding and the draughtsman*" at the December meeting of the Branch.

The subject of the paper is of particular interest to all concerned with promoting the use of better quality welding throughout industry. So much depends on the background and experience of designers and draughtsmen, and yet the field of welding expands so rapidly that often it is difficult for them to keep abreast of current practice. The little that has so far been written for their guidance often has too small a circulation, and quickly becomes out of date.

At the meeting representatives attended from many organizations, including the local technical college, and it was therefore possible for Mr. Merriman to be of assistance to a wide cross section of the welding industry. Whilst much of his material was drawn from his experience in the pressure vessel field, his remarks were of considerable value in many other directions. He emphasized the importance of avoiding stress concentrations through bad welding design, and also the dangers of 'overwelding'. In many cases, this led to an over-rigid design with undesirable consequences. Stress concentration factors were given for a number of typical joints and these became important in structures subject to fatigue loading, particularly where small weld defects, such as crater cracks, were apparent.

Mr. Merriman presented a number of graphs and diagrams illustrating methods of calculating the strength of various types of joint under different loadings, and reference may be made to the *British Welding Journal*, June 1959, for details. He also described a number of interesting details used in pressure vessel construction, such as austenitic–ferritic transitions in pipework and branches, attachment of linings to vessels, the welding of clad plate, and the welding of tubes to tube-plates.

A lively discussion followed Mr. Merriman's paper, and a vote of thanks to the speaker was proposed by Mr. R. van Etteger and seconded by Mr. A. J. Griffiths. B.K.B.

CHANGE OF ADDRESS

Solus-Schall Limited have removed their Sales and Administration Departments to County Building, Honeypot Lane, Stanmore, Middlesex. (Tel.: Wordsworth 4300.) The Service Department will remain at present at 15/18 Clipstone Street, London W.1.

DIARY

5th April — **East Midlands** — Annual General Meeting and films (Victoria Station Hotel, Nottingham, 7.15 p.m.)
North London (Slough Section)—"*Shop inspection of welds*" (Community Centre, Slough, 7.30 p.m.)

6th April—**South London (Medway Section)**—Annual General Meeting (Sun Hotel, Chatham, 7.30 p.m.)
Manchester—Annual General Meeting and film show (College of Technology, 7.15 p.m.)

7th April—**North Eastern (Tyneside)**—"*Ship steel*" by T. W. Bushell (Mining Institute, Neville Hall, Newcastle, 7.0 p.m.)

8th April—**Liverpool**—16th Annual Dinner to entertain the lecturers (St. George Restaurant)
Birmingham—Annual General Meeting and technical films (Grand Hotel, 7.30 p.m.)

11th April—**Sheffield**—Annual General Meeting and films (Grand Hotel, 7.15 p.m.)

12th April — **Leeds** — Annual General Meeting (Great Northern Hotel, 7.30 p.m.)
Liverpool—Annual General Meeting and film show (College of Technology, 7.30 p.m.)

13th April—**North Eastern (Tees-side)**—Annual General Meeting and Chairman's Address (Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.30 p.m.)
South London—A forum: "*Prospect for welding*" followed by Annual General Meeting (54 Princes Gate, 7.30 p.m.)
South Western—Annual General Meeting, 7.15 p.m.
East of Scotland—Annual General Meeting and film show, 7.30 p.m.
Wolverhampton—Annual General Meeting (Wulfrunian's Club, 7.30 p.m.)

20th April — **North London** — Annual General Meeting (54 Princes Gate, 7.30 p.m.)
West of Scotland—Annual General Meeting and film night (Institute of Engineers and Shipbuilders, Glasgow C.2, 7.0 p.m.)

21st April—**North London**—Joint Anual Dinner with South London Branch at Connaught Rooms.
Southern Counties—Annual General Meeting and films (Technical College, St. Mary's, Southampton)

valves at J. Blakeborough and Sons Ltd., Brighouse, Yorks.

Mr. Wood joined the British Aluminium Company in 1956 in the capacity of mechanical engineer and his responsibilities cover stress analysis, applications development, and fatigue investigations. He was elected to represent the South Buckinghamshire and Oxfordshire areas on the Eastern Branch Committee of the Institution of Mechanical Engineers' Graduate Section in 1959.

BRANCH NEWS

Joint London Branches Dinner

In 1959 the Annual Dinner of the North and South London Branches of the Institute was held during the Spring Meeting of the Institute and this added to the already large anticipated attendance of members and visitors.

However, the Dinner is fast becoming one of the most popular events in the welding field, and the Organizing Committee has therefore decided that the 1960 Dinner should be held in the Grand Hall of the Connaught Rooms. This can accommodate over 400 persons and will allow greater freedom in the choice of individual tables to seat parties of 8 or more people.

As in other years a room (this time the Balmoral Suite) will be available before and after the Dinner, so that members may meet each other informally. Space will be far less cramped than before.

One feature of this Joint Annual Dinner is that speeches are kept brief so as to allow the maximum time for this informal discussion; but it is understood that the Committee are hoping to be able to invite some interesting personalities as guests.

Members of the London Branches, and particularly those from other Branches, are heartily invited to attend this year's function, which will be held on Thursday, 21st April, 1960. Tickets (price 32*s.* 6*d.*) may be obtained from P. J. E. Heath, Esq., 33 Grosvenor Place, London, S.W.1.

East Midlands

A meeting of the Branch was held on Wednesday, 20th January, at the College, Loughborough, when a paper based on "*The Welding Fabrication connected with the British Transport Commission Diesel Development Programme*" was presented by Mr. G. Walton—a member of the Branch.

The paper related to the use of welding as a production tool in the manufacture of rolling stock, and it outlined the standard procedures of materials, electrodes, joint preparation, and control of metal deposition, which are carefully assessed and controlled, owing to their marked influence on welded structures.

The extensive use to which jigs and fixtures are employed was amply illustrated, the deciding factors influencing their use being:

(*a*) The control of distortion
(*b*) Ease of welding due to accessibility
(*c*) Reduction in handling time
(*d*) Enhanced overall productivity rates

The lecturer then went on to describe the construction of the principle details of diesel locomotives, types Bo-Bo and Co-Co at present being manufactured in both Crewe and Derby Locomotive Works.

It was clearly illustrated by means of slides the accuracy which can be obtained when constructing a 63 ft long diesel underframe. This has been possible as a result of co-ordination between the Design Office, Planning Office and Works. A limit of $\pm\frac{1}{16}$ in. in overall length was achieved in production.

The method of attaching the side skins to the superstructure to obtain a stable construction when the power equipment is added was explained, and the paper covered the construction of the standard design of an all-steel B.R. passenger coach. Slides clearly showed the extensive use of jigs, fixtures and registration equipment for accuracy of assembly to aid mass production.

Similar illustrations were used to describe the construction of 16-ton mineral wagons employing an all-welded body. Emphasis was laid on procedure control, welding standards, the methods of testing welders, and the assessment of the test welds. Testing was intended, primarily, to offer to operators an opportunity of examining their work critically, and, through discussion with the inspectors, to improve or maintain the standard of weld quality.

A stimulating discussion followed, which was felt to be a measure of the subject's interest to the members present.

G.W.

Manchester

For the fifth meeting of the Branch held on 6th January at the Manchester College of Science and Technology, members and visitors heard a paper entitled "*Inspection and Interpretation of Welding Codes*" by C. Atkinson, A.M.C.T.

The lecturer mentioned the multitude of codes which now exist relating to welding and emphasized the danger of just extracting and using such bits that would appear to satisfy a particular requirement. Visual inspection, with its many faults, had, as a result, led in certain quarters to deep-rooted objection to welding. What was the object of inspection? In Mr. Atkinson's view, it was to see if a weld was good enough for its job. For this, certain essentials had to be observed, among which were right material, correct preparation, root gap uniformity, and correct alignment. Welding procedure and welders' qualifications were equally important, and on the latter point Mr. Atkinson emphasized the need for welders to qualify under service conditions. Furthermore, the results of weld tests should be shown to welders as a means of obviating future failures.

Other points which had a bearing on the theme were put forward, such as preheating, post-welding inspection, post-heat treatment, correct electrode storage, adequate and efficient supervision on the actual job itself. Mr. Atkinson said that the formulation of a code to cover all allowable defects for welds in service was extremely difficult.

The lecturer illustrated his many points with slides, and very ably answered the questions put to him during the discussion time.

A.C.W.

North London

An excellent paper was presented by Mr. A. Prince at the meeting on Wednesday, 20th January, when he chose as his subject "*Further Developments in the Welding of Atomic Plant*". Very good support was given to this lecture, covering fabrication works at Hunterston, which was illustrated by slides. Types of steel used, and the various forged fittings of both British and European origin, were discussed. The electro-slag method was covered and the points regarding all-positional welding, on such things as spheres, were mentioned. Accent was laid on the stress relief of weldments at site, and the change in results where different temperatures in the range 550–650°C. were used. Mr. Prince emphasized the need for a standard covering atomic power work.

In the interesting question time which followed the lecturer proved to be a master of his subject, and dealt most ably with the controversial points raised. Many important companies, interested in this field, were represented in the large number of engineers present.

R.B.W.

Sheffield

Annual Dinner

The Branch held its thirteenth Annual Dinner at the Royal Victoria Hotel on Monday, 4th January. Nearly 200 members and guests attended, and Mr. A. Robert Jenkins, J.P., the Branch President, was in the chair.

The toast of the Institute of Welding and the Branch was proposed by the

The Branch Chairman, S. B. Rippon, J.P., the Institute President, E. Seymour-Semper, and the Branch President, A. Robert Jenkins, J.P. at the Sheffield and District Annual Dinner

Master Cutler, Mr. P. J. C. Bovill, J.P. In his response the President of the Institute, Mr. E. Seymour-Semper, appealed for the energetic support of all members of the Institute in ensuring adequate advanced instruction for welding specialists, for whom the universities and technical colleges at present make no provision.

The toast of the guests was proposed by Mr. S. B. Rippon, J.P., the Branch Chairman, and the response was made by the Lord Mayor of Sheffield, Alderman A. V. Wolstenholme.

High Vacuum

The Annual Joint Meeting between the Branch and the Rotherham Engineering Society was held on 11th January in the Assembly Hall at the Rotherham Technical College. Mr. S. B. Rippon, J.P. (Branch Chairman) took the Chair.

"*High Vacuum, its Production and Use*" was very clearly explained by Mr. L. G. Beckett of E. Edwards High Vacuum Ltd. Slides, a film, and a most impressive array of equipment were used as visual aids and for practical demonstrations.

The meeting was attended by 86 members and visitors and Mr. Beckett ably dealt with questions from the audience to conclude a most interesting and educating evening.

Wolverhampton

Mr. H. B. Merriman presented his paper entitled "*Welding and the draughtsman*" at the December meeting of the Branch.

The subject of the paper is of particular interest to all concerned with promoting the use of better quality welding throughout industry. So much depends on the background and experience of designers and draughtsmen, and yet the field of welding expands so rapidly that often it is difficult for them to keep abreast of current practice. The little that has so far been written for their guidance often has too small a circulation, and quickly becomes out of date.

At the meeting representatives attended from many organizations, including the local technical college, and it was therefore possible for Mr. Merriman to be of assistance to a wide cross section of the welding industry. Whilst much of his material was drawn from his experience in the pressure vessel field, his remarks were of considerable value in many other directions. He emphasized the importance of avoiding stress concentrations through bad welding design, and also the dangers of 'overwelding'. In many cases, this led to an over-rigid design with undesirable consequences. Stress concentration factors were given for a number of typical joints and these became important in structures subject to fatigue loading, particularly where small weld defects, such as crater cracks, were apparent.

Mr. Merriman presented a number of graphs and diagrams illustrating methods of calculating the strength of various types of joint under different loadings, and reference may be made to the *British Welding Journal*, June 1959, for details. He also described a number of interesting details used in pressure vessel construction, such as austenitic–ferritic transitions in pipework and branches, attachment of linings to vessels, the welding of clad plate, and the welding of tubes to tube-plates.

A lively discussion followed Mr. Merriman's paper, and a vote of thanks to the speaker was proposed by Mr. R. van Etteger and seconded by Mr. A. J. Griffiths. B.K.B.

CHANGE OF ADDRESS

Solus-Schall Limited have removed their Sales and Administration Departments to County Building, Honeypot Lane, Stanmore, Middlesex. (Tel.: Wordsworth 4300.) The Service Department will remain at present at 15/18 Clipstone Street, London W.1.

DIARY

5th April — East Midlands — Annual General Meeting and films (Victoria Station Hotel, Nottingham, 7.15 p.m.)
North London (Slough Section)—"*Shop inspection of welds*" (Community Centre, Slough, 7.30 p.m.)

6th April—South London (Medway Section)—Annual General Meeting (Sun Hotel, Chatham, 7.30 p.m.)
Manchester—Annual General Meeting and film show (College of Technology, 7.15 p.m.)

7th April—North Eastern (Tyneside)—"*Ship steel*" by T. W. Bushell (Mining Institute, Neville Hall, Newcastle, 7.0 p.m.)

8th April—Liverpool—16th Annual Dinner to entertain the lecturers (St. George Restaurant)
Birmingham—Annual General Meeting and technical films (Grand Hotel, 7.30 p.m.)

11th April—Sheffield—Annual General Meeting and films (Grand Hotel, 7.15 p.m.)

12th April — Leeds — Annual General Meeting (Great Northern Hotel, 7.30 p.m.)
Liverpool—Annual General Meeting and film show (College of Technology, 7.30 p.m.)

13th April—North Eastern (Tees-side)—Annual General Meeting and Chairman's Address (Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.30 p.m.)
South London—A forum: "*Prospect for welding*" followed by Annual General Meeting (54 Princes Gate, 7.30 p.m.)
South Western—Annual General Meeting, 7.15 p.m.
East of Scotland—Annual General Meeting and film show, 7.30 p.m.
Wolverhampton—Annual General Meeting (Wulfrunian's Club, 7.30 p.m.)

20th April — North London — Annual General Meeting (54 Princes Gate, 7.30 p.m.)
West of Scotland—Annual General Meeting and film night (Institute of Engineers and Shipbuilders, Glasgow C.2, 7.0 p.m.)

21st April—North London—Joint Anual Dinner with South London Branch at Connaught Rooms.
Southern Counties—Annual General Meeting and films (Technical College, St. Mary's, Southampton)

Current WELDING LITERATURE

Book Reviews
Additions to the Institute Library
Trade Publications

CONTENTS OF PERIODICALS RECEIVED

This section is intended to give a survey of the current welding literature received by the Institute of Welding Library. The contents lists are not exhaustive; only the main articles in welding journals are listed, and reprints from other journals and short notes are generally excluded. In addition, welding articles from other periodicals are listed. Abstracts of welding literature are given in the Bibliographical Bulletin of Welding and Allied Processes, *published by the International Institute of Welding, and details of this may be obtained from the Secretary of the Institute of Welding.*

Welding Journals

Canadian Welder, 1959, vol. 50, October

Recommended radiographic inspection practice (8–11)
Health hazards in welding, W. Schweisheimer (12–15)
New design in elevated water tanks (16–18)
Completely automated soldering system (20)

Canadian Welder, 1959, vol. 50, November

Maintenance welding; key to cost reduction (10–11, 14–15)
Welded studs make bridge safer (18)

Japan Welding Society Journal, 1959, vol. 28, October

"Back Wave" technique by arc welding electrode and its application, S. Kimura and K. Hayashi (3–10)
Three phase low frequency resistance welder, T. Nakamura and S. Yamaguchi (11–19)
A metallurgical study on the weld heat affected zone with a reproducing apparatus for weld thermal cycles, Report 5, H. Suzuki and H. Tamura (20–26)
Studies of non-metallic inclusions in basic weld metal, Report 6, H. Sakaki (27–30)
Welding of plastics, Part 3, I. Onishi and H. Kimura (41–44)

Japan Welding Society Journal, 1959, vol. 28, November

Magnetic particle inspection method and penetrant inspection method, S. Shimazu (3–10)
Hot ductility of stainless steels during weld thermal cycle; Report 1, H. Suzuki and others (18–24)
The shapes and compositions of non-metallic inclusions in mild steel weld metals; Report 2, K. Kato (25–30)
Continuously cooling transformation diagrams of various steels submitted to welding; Report 5, H. Sekiguchi and M. Inagaki (31–38)
Continuous cooling transformation diagrams of various steels submitted to welding; Report 6, H. Sekiguchi and M. Inagaki (39–46)
Study on welding of low alloy high strength steels; Report 4, Y. Ito and others (47–54)
Data used for the stationary acetylene generating apparatus; Report 3, I. Ueda and others (55–58)

Przeglad Spawalnictwa (Poland), 1959, vol. 11, Oct.–Nov.

Problems of brittle fracture in welded steel structures, A. A. Wells (267–271)
Welded structures evaluation, W. Soete (272–275)
Influence of welding stresses on brittle fracture initiation in welded structures, A. Fabiszewski (276–280)
Problems of welding fracture in ships in the light of latest investigations and codes: discussion, E. Bargiel (280–282, 282–285)
For the proper evaluation of welding work quality in shipbuilding, M. Mysliwiec (286–290)
Electrodes in shipbuilding, F. Richter (290–296)
Choice of economic method of weldment inspection in shipbuilding, M. Jakubiec (297–303)
Economy in steel St 52 application in welded structures, A. Neumann (303–307)
Results of tests on flame-cutting improvement and on gas economy, W. Schierhorn (308–310)
Application and output of flame-cutting automatic machinery, K. Schindler (310–312)
Technology of welding on slipway timber cargo ship B514-5900 TDW, Z. Unterschutz (312–314)

Przeglad Spawalnictwa (Poland), 1959, vol. 11, December

New hypothesis on hydrogen and on gas pockets in welds; Part 1, J. Wegrzyn
The welding of magnesium alloys; Part 1, A. Ciszewski and T. Radomski

Przeglad Spawalnictwa (Poland), 1960, vol. 12, January

New hypothesis on hydrogen and on gas pockets in welds; Part 2, J. Wegrzyn
The welding of magnesium alloys; Part 2, A. Ciszewski and T. Radomski
On spot weld strength, S. Kocanda
Fatigue tests of beams with welded gusset plates, Z. K. Lesniak

Schweissen und Schneiden (Germany), 1959, vol. 11, November

Principles and development of the quality coefficient for welded seams in pressure vessels, E. Rubo (409–415)

Welding of ferritic annealed nodular cast iron, W. Zitzelsberger (416–427)

Welded railway bridges in Poland, Z. K. Lesniak (428–432)

Hard surfacing of machine parts and tools with welding blowpipe, H. Killing (432–436)

Experiences in judging the ability of welders, R. Faulstich (437–438)

Schweissen und Schneiden (Germany), 1959, vol. 11, December

Contribution to the problem of changing the deposition characteristics of coated electrodes by means of changes in the electric circuit, F. Erdmann-Jesnitzer and H. E. Weinschenk (447–454)

The correct application of high quality-coefficient for welds in pressure vessels, E. Rubo (455–458)

Influence of welding conditions upon the wearing properties of hard faced surfaces, K. Wellinger and H. Uetz (458–474)

Experiments with a new type of semi-automatic submerged arc welding equipment with pneumatic flux feeding, H. von Hofe (475–479)

Welding repairs on haematite castings in steelworks and mines, C. Chr. Elster (480–482)

Schweisstechnik (Berlin), 1959, vol. 9, November

Strength of fillet welds under combined loads, A. Neumann and H. Ziethe (402–405)

Hard facing of drop forging tools, B. Zorkoczy (406–410)

Economical welding in the production line, W. Anders (401)

The welding of high alloy steels with special reference to corrosion, H. Jahre (411–415)

Ways to solve the economical main task are shown by the instruction show of standardisation, W. Zeitel (419–421)

Welding blow pipe reduction equipment, W. Ribmann (422)

UPHK-welding equipment used in the motor car industry, B. Heinze (425)

Welding design of electromotors for shipbuilding, W. Sauerzapf (426)

Schweisstechnik (Berlin), 1959, vol. 9, December

Economics and technology of resistance welding, W. Gilde (433–436)

The loading capacity of resistance welding machines, A. Rieden (437–440)

On resistance welding controls, H. Warenski (441–445)

Resistance welding in the assembly-line production of automobiles, F. Klasterka (446–449)

The application of flash-butt welding to the construction of chemical plant and equipment, F. Bielek (449–452)

Hard facing of drop-forging tools; Part II, B. Zorkoczy (455–457)

Resistance welding carried out on very small parts, G. Deubel (452–455)

The evaluation of gray cast iron welding rods, F. Wuttke (457–462)

Soudage et Techniques Connexes (Paris), 1959, vol. 13, Nov.–Dec.

Flash welding in aeronautics, C. Elghozi (405–418)

Comparative tests of spot welded or riveted components for aircraft construction, R. Cazaud (419–422)

Stress corrosion of steel, H. Gerbeaux (433–472)

South African Institution of Welding, Monthly Bulletin, 1959, October

Radiographic inspection of steel pipes, Part 2, (3–8)

The "Dip Transfer" process (9–11)

The Stabilizer (Lincoln Electric Co. Ltd.), 1959, vol. 26 mid-December

Caterpillar: speed production with Lincolnweld (7–10)

Varilna Technika (Yugoslavia), 1959, vol. 8, No. 3

Welding and weldability of plastics, F. Gosar (75–80)

The Welder, 1959, vol. 28, July/September

Giant welded wind tunnels at Bedford (46–50)

Large all-welded distillation columns (51–52)

Some aspects of the radiography of thick plate welds, E. H. van Someren (53–55)

The metal-arc welding of stainless steels; Part II. The choice of base metal, electrodes and welding procedure for stainless and high nickel alloys in various combinations, M. C. T. Bystram (56–62)

Welding Design and Fabrication (U.S.A.), 1959, vol. 29, November

Redesign eliminates straightening and grinding; weldment cost is cut 50%, H. J. Wilson (49)

Standard structural shapes can simplify design of machine bases, A. E. Dorod (50–1)

Welded-steel design makes new lathe stronger, lighter, more economical, J. M. Little (52–3, 82)

Practical hints on designing and ordering welded pressure vessels, R. Chuse (54, 80)

Savannah's nuclear power plant is housed in a 500,000 lb welded fabrication, H. Lefer (56–7, 80)

Spot welded paper-thin steel withstands 305,000 p.s.i. pressure, (58–9)

Redesigned transformer cases calls for welded aluminium instead of steel, C. Bastion (60, 80)

Simplified design cuts cost of second all-welded geodesic dome building (63–5)

Three ways to sell structural welding to designers and engineers, J. R. Warn (66, 68)

Quality control system governs each step in production of welded steel tubing (70–2, 78)

GMC uses statistical methods to improve projection weld quality (73–75)

Welding Design and Fabrication (U.S.A.), 1959, vol. 32, December

U.S. will design close to 41,000 welded highway bridges in the next 15 years (30–31, 59)

On-the-job heat treating used in repair of brittle stainless valves, J. L. McParlan and M. J. Ryan (42–43, 58)

Special automatic set-ups speed welding of 18-miles of 78-inch pipe (44–45)

Vacuum brazing of stainless honeycomb panels solves oxidation problem (46–48)

Welding Engineer (U.S.A.), 1959, vol. 44, November

Specifications developed for production welding of thoriated magnesium, H. Meredith (29–31)

The double edge sword—another view of stress relieving, L. J. Larson (32–34)

Spot welding procedures and design, Part 2, L. F. Spencer (35–37)

Procedures for welding 17–4 PH stainless steel, G. E. Linnert (38–40)

Extensive tests show that a new aluminium alloy is not prone to brittle fracture, R. D. Olleman and G. C. Wolfer (42–45)

Plastic welding fixtures add light-weight preciseness to manufacturing operations, J. Delmonte (66–67)

Welding Engineer (U.S.A.), 1959, vol. 44, December

Welding safety "why's" (29–32)

Foil-gage steel rocket chambers spot welded (40, 42)

Semiautomation in resistance welders, D. D. Williams (46–47)

Welding Journal (U.S.A.), 1959, vol. 38, November

High-frequency induction brazing and soldering find application in many industries concerned with metal fabrication, J. Libsch and P. Capolongo (1059–1069)

Continuous research and development in the field of metals joining extend the use of arc welding processes and equipment for automation, F. E. Adamson (1070–1079)

Transformers for resistance-welding machines, J. J. Riley (1080–1090)

Joining braided wire to heavy casting "couldn't be done" but . . . C. Bastion (1093)

Welded continuous frames and their components, Progress report No. 32. Corner connections loaded in tension, J. W. Fisher and G. C. Driscoll (425s–434s)

Effect of microstructure on notch toughness—Part IV, E. H. Kottcamp and R. D. Stout (435s–440s)

Evaluation of weld-joint flaws as initiating points of brittle fracture, Part II, R. P. Sopher and others (441s–450s)

Brittle-fracture strength of welded spherical container, H. Kihara and others (451s–456s)

Welding Journal (U.S.A.), 1959, vol. 38, December

Tungsten-arc welding of tantalum, L. R. Haslip and B. S. Payne (1165–1174)

Tungsten-arc welding the root pass of power-pipe joints, R. W. Bennett (1175–1181)

Control of process variables—key to the successful welding of foil, J. Campbell (1182–1191)

Elevated-temperature properties of modified type 347 weld metals, T. J. Moore (457*s*–474*s*)

Transformer behaviour of Mn-Mo armor steels, E. F. Nippes, W. F. Savage and J. M. Paez (475*s*–481*s*)

New developments in brazing high-temperature nickel-base alloys, E. H. Kinelski and J. B. Adamec (482*s*–486*s*)

Effect of arsenic on weldability and notch toughness of mild steel (487*s*–496*s*)

Welding and Metal Fabrication, 1959, vol. 27, November

The "Oriana"—A 1,000-ton welded aluminium superstructure makes shipbuilding history (398–406)

Honeycomb sandwich structures, G. S. Newell (407–411)

Developments in metal cutting and shaping (412–417)

The coming "air-cars" (418–419)

The rising characteristic D.C. power source—its effect on self-adjustment in the inert-gas metal-arc welding of aluminium, R. A. Cresswell and J. A. Sheward (420–429)

Automatic vertical welding of thick plate, the Rockweld-Vus Vertomatic process (430–432)

Welding and Metal Fabrication, 1960, vol. 28, January

The production of cable chains (2–8)

Submerged-arc welding of low alloy steel sheet: 2—Development of production welding techniques, C. A. Terry and A. B. Tinsley (9–15)

Fabricating components for commercial vehicles. Details of press-work and welding methods at British Light Steel Pressings Ltd., T. J. Palmer (16–21)

The organization of a modern fabrication shop, A. G. Thompson (24–28)

Recent developments in heavy fabrication practice: 2, A. D. Barker (29–27)

Oxygen-cutting and castellated beams, A. L. Chappell (38–39)

Welding News (Holland), 1959, No. 104, September

CO_2 welding with protruding contact tube, J. Camerlink (4)

Looking around at a crane builder's, J. W. A. Stemerdink (5–7)

Welding Research Abroad (U.S.A.), 1959, vol. 5, December

IIW Document No. X-218-59. Effect of stress relieving on brittle fracture strength of welded steel plate, H. Kihara and others (40–49)

Cold arc welding of gray cast iron using a granular flux and gray-iron electrodes, A. I. Zelenov, trans. by H. Brutcher from *Avtogennoe Delo*, 1953, p. 7–9 (50–58)

IIW Commission VIII. "Hygiene and Safety", Annual report (58–9)

IIW Commission V. "Testing, measurement and control of welds", Annual report (60–65)

IIW Commission VII. "Standardization", Annual report (65–9)

IIW Commission IX. "Behaviour of metals subjected to welding" Recommendations for the choice and classification of steels for use in welded structure (70–7)

IIW Commission XIV. "Welding Instruction". Recommended rules for the qualification of welders—manual metal-arc welding and gas welding of steel (78–80)

Zeitschrift für Schweisstechnik (Switzerland), 1959, vol. 49, December

The motor boat "Schwyz", E. Herzog (350–353)

The most important faults in oxy-acetylene welding, H. Ehrenberg and H. Schmidt (354–362)

Test to determine the variation in pressure in a bottle of dissolved acetylene in heating relative to climatic conditions, P. Walthery (362–365)

Zvaranie (Czechoslovakia), 1959, vol. 8, November

Weldability tests of chrome-nickel steels and electrodes, J. Nemec (321–328)

Internal stress influence on the fatigue limit of structural materials, O. Izdinsky (328–335)

The employment of welding in brass strip rolling mills, V. Orszagh (337–344)

Welding with fully coated electrodes, P. Hrbal (344–347)

Principles of correct connection of resistance welding machines with the electrical network, L. Pliva (348–351)

Zvaranie (Czechoslovakia), 1959, vol. 8, December

The technical development of welding—our nearest aim, B. Vrana (353–354)

The development of welding techniques in the U.S.S.R. during the next period (354–355)

Application field of automatic electro-slag welding, M. Mosny (356–359)

Cored electrodes for CO_2-shielded welding, L. Lakatos and T. Koromzay (359–363)

Manual electro-slag welding, O. Zakavec (364–370)

Working risk in welding with basic electrodes, M. Barborik, L. Hanslian and O. Charamza (372–374)

Other Journals

Fluoroscopic inspection—Technique developed for brazed stainless-steel honeycomb-sandwich panels, W. R. Bear and W. S. Diehl (*Aircraft Production*, 1959, vol. 21, November, pp. 370–373)

New developments in welding stainless steels, G. E. Linnert (*Metal Progress* (U.S.A.), 1959, vol. 75, June, pp. 127–128)

Fabricator scores breakthrough in joining titanium clad steel (*Steel* (U.S.A.), 1959, vol. 145, October 19, pp. 152–153)

Designed for service at −320°F 9% nickel steel is strong, weldable, easily formed, W. H. Funk (*Materials in Design Engineering*, 1959, vol. 50, October, pp. 135–136)

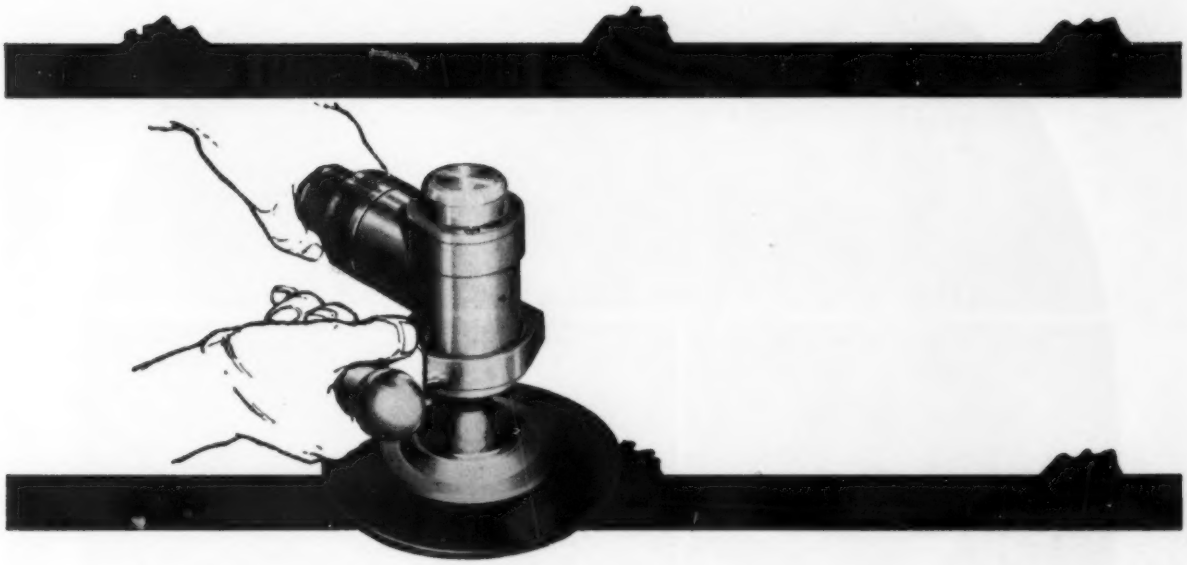
Welding dissimilar metals, British Welding Research Association (*Engineering*, 1959, vol. 188, October 16, p. 355)

Magnesium in aeronautics and nuclear engineering, Part I, Properties of Alloys, E. F. Emley (*Light Metals*, 1959, vol. 22, October, pp. 242–246)

Magnesium in aeronautics and nuclear engineering, Part 2. Fabrication and production, E. F. Emley (*Light Metals*, 1959, vol. 22, November, pp. 258–259)

Welding nuclear power equipment, R. Sutton (*Metal Progress* (U.S.A.), 1959, vol. 75, June, pp. 124–126)

Taking the rough with the smooth...



CARBOFLEX wheels mean more speed, more safety and more economy in weld-dressing operations of all kinds. The resilience of CARBOFLEX depressed-centre wheels gives maximum tolerance to careless handling or unavoidable shocks: speeds up to 16,000 s.f.p.m. may safely be used. There is no more versatile tool. An easily chamfered edge cuts away excess weld almost fiercely, yet leaves a smooth undamaged surface. CARBOFLEX depressed-centre wheels have a multitude of uses including de-scaling and de-burring, smoothing flame-cut edges, cutting sheet metal, grooving seams for welding, bevelling sheet metal, and cleaning up castings. They are most useful tools in any welding shop.

CARBOFLEX is a registered trade mark of the Carborundum Company Limited.

CARBOFLEX DEPRESSED-CENTRE WHEELS

Abrasive products by **CARBORUNDUM**
TRADE MARK

THE CARBORUNDUM COMPANY LIMITED, TRAFFORD PARK, MANCHESTER 17

Welding Journal (U.S.A.), 1959, vol. 38, November

High-frequency induction brazing and soldering find application in many industries concerned with metal fabrication, J. Libsch and P. Capolongo (1059–1069)

Continuous research and development in the field of metals joining extend the use of arc welding processes and equipment for automation, F. E. Adamson (1070–1079)

Transformers for resistance-welding machines, J. J. Riley (1080–1090)

Joining braided wire to heavy casting "couldn't be done" but . . . C. Bastion (1093)

Welded continuous frames and their components, Progress report No. 32. Corner connections loaded in tension, J. W. Fisher and G. C. Driscoll (425*s*–434*s*)

Effect of microstructure on notch toughness—Part IV, E. H. Kottcamp and R. D. Stout (435*s*–440*s*)

Evaluation of weld-joint flaws as initiating points of brittle fracture, Part II, R. P. Sopher and others (441*s*–450*s*)

Brittle-fracture strength of welded spherical container, H. Kihara and others (451*s*–456*s*)

Welding Journal (U.S.A.), 1959, vol. 38, December

Tungsten-arc welding of tantalum, L. R. Haslip and B. S. Payne (1165–1174)

Tungsten-arc welding the root pass of power-pipe joints, R. W. Bennett (1175–1181)

Control of process variables—key to the successful welding of foil, J. Campbell (1182–1191)

Elevated-temperature properties of modified type 347 weld metals, T. J. Moore (457*s*–474*s*)

Transformer behaviour of Mn-Mo armor steels, E. F. Nippes, W. F. Savage and J. M. Paez (475*s*–481*s*)

New developments in brazing high-temperature nickel-base alloys, E. H. Kinelski and J. B. Adamec (482*s*–486*s*)

Effect of arsenic on weldability and notch toughness of mild steel (487*s*–496*s*)

Welding and Metal Fabrication, 1959, vol. 27, November

The "Oriana"—A 1,000-ton welded aluminium superstructure makes shipbuilding history (398–406)

Honeycomb sandwich structures, G. S. Newell (407–411)

Developments in metal cutting and shaping (412–417)

The coming "air-cars" (418–419)

The rising characteristic D.C. power source—its effect on self-adjustment in the inert-gas metal-arc welding of aluminium, R. A. Cresswell and J. A. Sheward (420–429)

Automatic vertical welding of thick plate, the Rockweld-Vus Vertomatic process (430–432)

Welding and Metal Fabrication, 1960, vol. 28, January

The production of cable chains (2–8)

Submerged-arc welding of low alloy steel sheet: 2—Development of production welding techniques, C. A. Terry and A. B. Tinsley (9–15)

Fabricating components for commercial vehicles. Details of press-work and welding methods at British Light Steel Pressings Ltd., T. J. Palmer (16–21)

The organization of a modern fabrication shop, A. G. Thompson (24–28)

Recent developments in heavy fabrication practice: 2, A. D. Barker (29–27)

Oxygen-cutting and castellated beams, A. L. Chappell (38–39)

Welding News (Holland), 1959, No. 104, September

CO_2 welding with protruding contact tube, J. Camerlink (4)

Looking around at a crane builder's, J. W. A. Stemerdink (5–7)

Welding Research Abroad (U.S.A.), 1959, vol. 5, December

IIW Document No. X-218-59. Effect of stress relieving on brittle fracture strength of welded steel plate, H. Kihara and others (40–49)

Cold arc welding of gray cast iron using a granular flux and gray-iron electrodes, A. I. Zelenov, trans. by H. Brutcher from *Avtogennoe Delo*, 1953, p. 7–9 (50–58)

IIW Commission VIII. "Hygiene and Safety", Annual report (58–9)

IIW Commission V. "Testing, measurement and control of welds", Annual report (60–65)

IIW Commission VII. "Standardization", Annual report (65–9)

IIW Commission IX. "Behaviour of metals subjected to welding" Recommendations for the choice and classification of steels for use in welded structure (70–7)

IIW Commission XIV. "Welding Instruction". Recommended rules for the qualification of welders—manual metal-arc welding and gas welding of steel (78–80)

Zeitschrift für Schweisstechnik (Switzerland), 1959, vol. 49, December

The motor boat "Schwyz", E. Herzog (350–353)

The most important faults in oxy-acetylene welding, H. Ehrenberg and H. Schmidt (354–362)

Test to determine the variation in pressure in a bottle of dissolved acetylene in heating relative to climatic conditions, P. Walthery (362–365)

Zvaranie (Czechoslovakia), 1959, vol. 8, November

Weldability tests of chrome-nickel steels and electrodes, J. Nemec (321–328)

Internal stress influence on the fatigue limit of structural materials, O. Izdinsky (328–335)

The employment of welding in brass strip rolling mills, V. Orszagh (337–344)

Welding with fully coated electrodes, P. Hrbal (344–347)

Principles of correct connection of resistance welding machines with the electrical network, L. Pliva (348–351)

Zvaranie (Czechoslovakia), 1959, vol. 8, December

The technical development of welding—our nearest aim, B. Vrana (353–354)

The development of welding techniques in the U.S.S.R. during the next period (354–355)

Application field of automatic electro-slag welding, M. Mosny (356–359)

Cored electrodes for CO_2-shielded welding, L. Lakatos and T. Koromzay (359–363)

Manual electro-slag welding, O. Zakavec (364–370)

Working risk in welding with basic electrodes, M. Barborik, L. Hanslian and O. Charamza (372–374)

Other Journals

Fluoroscopic inspection—Technique developed for brazed stainless-steel honeycomb-sandwich panels, W. R. Bear and W. S. Diehl (*Aircraft Production*, 1959, vol. 21, November, pp. 370–373)

New developments in welding stainless steels, G. E. Linnert (*Metal Progress* (U.S.A.), 1959, vol. 75, June, pp. 127–128)

Fabricator scores breakthrough in joining titanium clad steel (*Steel* (U.S.A.), 1959, vol. 145, October 19, pp. 152–153)

Designed for service at −320°F 9% nickel steel is strong, weldable, easily formed, W. H. Funk (*Materials in Design Engineering*, 1959, vol. 50, October, pp. 135–136)

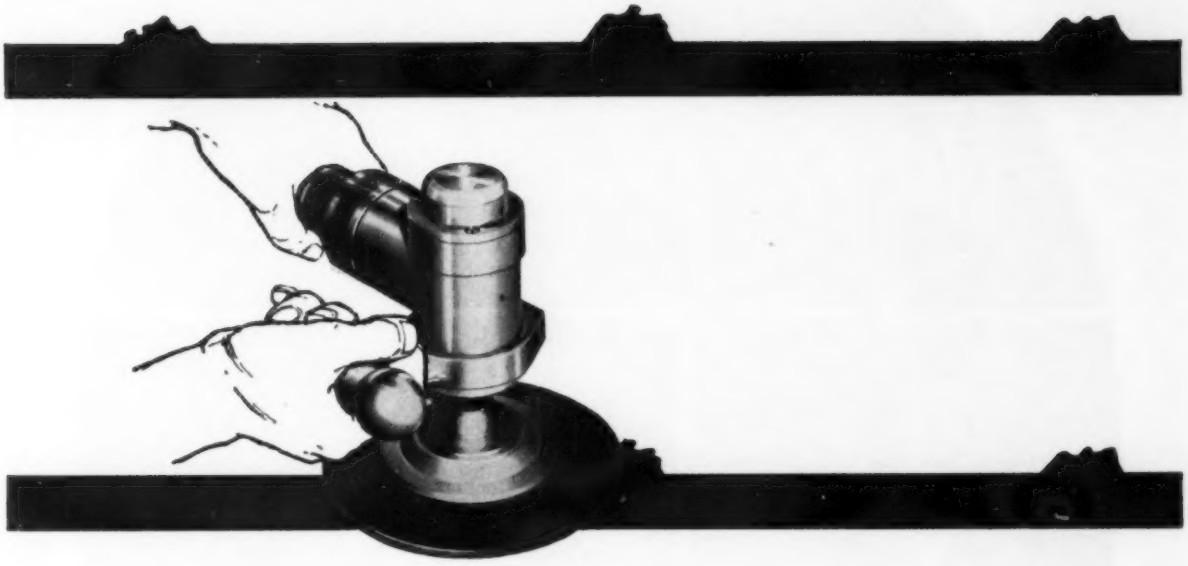
Welding dissimilar metals, British Welding Research Association (*Engineering*, 1959, vol. 188, October 16, p. 355)

Magnesium in aeronautics and nuclear engineering, Part I, Properties of Alloys, E. F. Emley (*Light Metals*, 1959, vol. 22, October, pp. 242–246)

Magnesium in aeronautics and nuclear engineering, Part 2. Fabrication and production, E. F. Emley (*Light Metals*, 1959, vol. 22, November, pp. 258–259)

Welding nuclear power equipment, R. Sutton (*Metal Progress* (U.S.A.), 1959, vol. 75, June, pp. 124–126)

Taking the rough with the smooth...



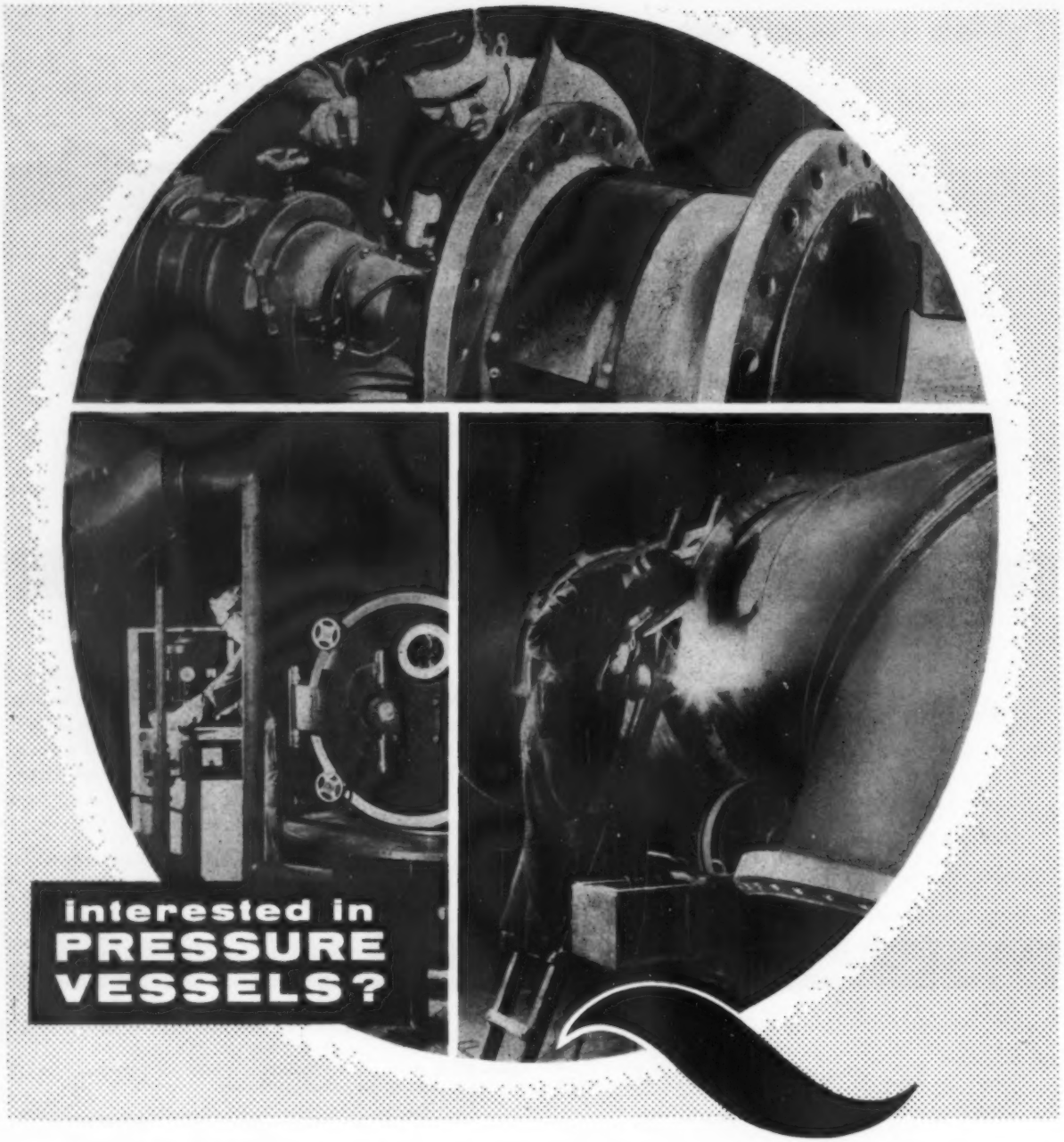
CARBOFLEX wheels mean more speed, more safety and more economy in weld-dressing operations of all kinds. The resilience of CARBOFLEX depressed-centre wheels gives maximum tolerance to careless handling or unavoidable shocks: speeds up to 16,000 s.f.p.m. may safely be used. There is no more versatile tool. An easily chamfered edge cuts away excess weld almost fiercely, yet leaves a smooth undamaged surface. CARBOFLEX depressed-centre wheels have a multitude of uses including de-scaling and de-burring, smoothing flame-cut edges, cutting sheet metal, grooving seams for welding, bevelling sheet metal, and cleaning up castings. They are most useful tools in any welding shop.

CARBOFLEX is a registered trade mark of the Carborundum Company Limited.

CARBOFLEX DEPRESSED-CENTRE WHEELS

Abrasive products by **CARBORUNDUM**
TRADE MARK

THE CARBORUNDUM COMPANY LIMITED, TRAFFORD PARK, MANCHESTER 17



If you are, you probably already know that Jenkins of Rotherham have the capacity, the co-ordinated production and advanced techniques successfully to undertake and expedite the fabrication of vessels of any design in any weldable metal.

JENKINS
of Rotherham

Welded fabrications and fusion-welded pressure vessels to the requirements of Lloyds Class 1, A.S.M.E., A.O.T.C. codes and similar specifications

WELDED PRESSURE VESSELS IN STAINLESS STEEL, MONEL, TITANIUM, HEAVY ALUMINIUM AND MILD STEEL

ROBERT JENKINS & CO. LIMITED ROTHERHAM

Telephone: 4201–6 (6 Lines)

IVANHOE

THE SIGN OF GOOD WELDING

only FIRTH-VICKERS make

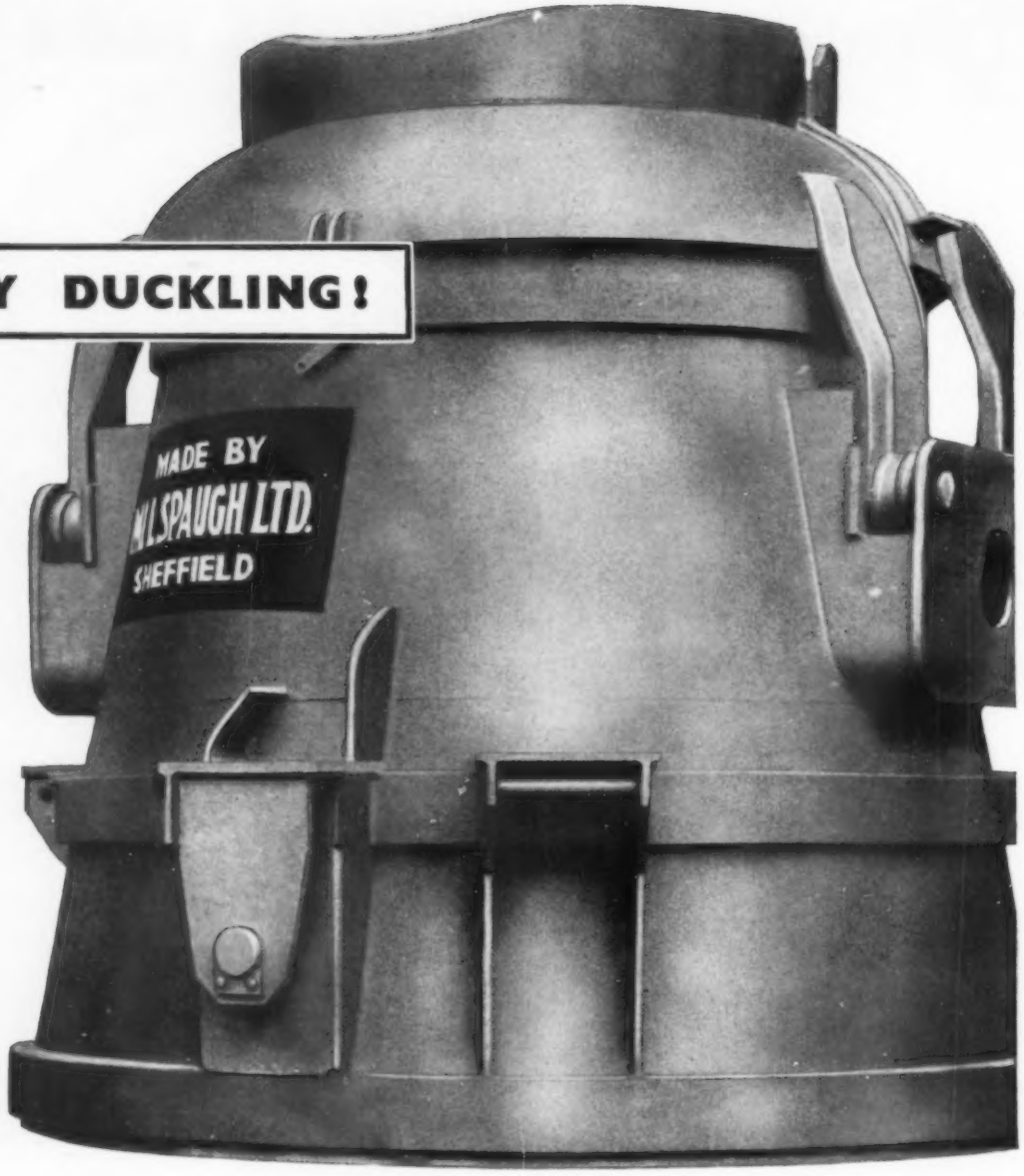
For over 25 years 'Staybrite' F.D.P. steel has been the standard material in the construction of a wide range of chemical plant. It is also used for storage and transport in the chemical, dairy and brewing industries, and is extensively applied in all types of power production.

Technical information on the use of all Firth-Vickers steels, together with technical literature are always available on request.

FIRTH-VICKERS STAINLESS STEELS LTD., SHEFFIELD

is the only Company in Europe to devote its activities exclusively to the production and development of stainless and heat-resisting steels.

UGLY DUCKLING!



But not an odd one out at Millspaugh. This charging bucket is a typical heavy-duty fabrication built by Millspaugh for the Steel Industry. Millspaugh research, Millspaugh know-how, Millspaugh brains and brawn, producing fabrications to be relied on, are a big part of to-day's industrial scene.

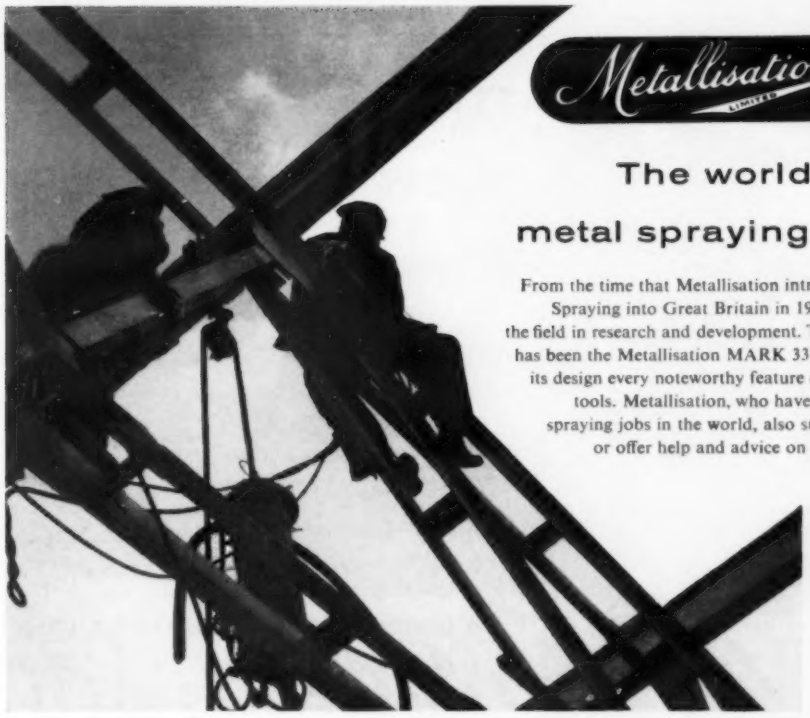
One of a number of M.S. Charging Buckets built recently by Millspaugh Ltd. This one is 11 ft. dia. by 10 ft. deep.

WELDING AND FABRICATIONS BY **MILLSPAUGH** SHEFFIELD

MILLSPAUGH LIMITED, ALSING ROAD, SHEFFIELD 9.
Tel: 42411 (5 lines). Telex. 54-107
LONDON SALES OFFICE: 22 CARLTON HOUSE TERRACE, S.W.1.
Tel: WHItehall 7107

MEMBER OF THE HADFIELDS GROUP

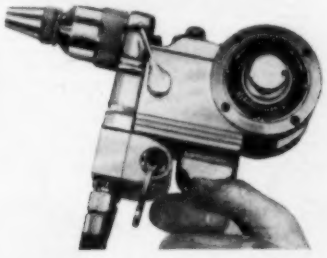
LONDON · PARIS · ROUEN · MONTREAL · OWEN SOUND



Metallisation LIMITED

The world's foremost metal spraying specialists

From the time that Metallisation introduced the process of Metal Spraying into Great Britain in 1922 they have continually led the field in research and development. The most recent introduction has been the Metallisation MARK 33 pistol which incorporates in its design every noteworthy feature of the best in metal spraying tools. Metallisation, who have completed the largest metal spraying jobs in the world, also supply complete equipment—or offer help and advice on metal spraying applications.



Head Office: METALLISATION LTD., BARCLAYS BANK CHAMBERS, DUDLEY WORCS. *Telephone: Dudley 53221/2*
London: 171 Palace Chambers, Bridge Street, S.W.1. Telephone: Whitehall 2868 *Scotland: Metallisation (Scotland) Ltd., Ballochmill Road, Rutherglen. Telephone: Rutherglen 1910*
N.E. Coast: Portrack Lane Industrial Estate, Stockton-on-Tees. Telephone: Stockton-on-Tees 64585

M.W.14.

"TAKE MY TIP— USE SIFBRONZE EQUIPMENT!"

says Will the Welder

"DEMON" BLOWPIPES:—
General Duty and Cutting Models.

SIF-COLIBRI CUTTING MACHINE
The clockwork machine which turns a hand cutter into a precision machine cutter. Ideal for flame cutting on site.

SIF-COMBI PROFILE CUTTING MACHINE
An automatic dual-purpose machine for all kinds of cutting work.

SIFBRONZE REGULATORS
Modern precision instruments giving constant pressure and volume.

SIFBRONZE CATSEYE GOGGLES
The most advanced type on the market.

If you want to know how Sifbronze equipment can help you, fill in the coupon right away.

SUFFOLK IRON FOUNDRY [1920] Ltd., Stowmarket, Suffolk.

Please send me leaflets detailing Sifbronze equipment.

NAME .....

ADDRESS .....

.....

BWJ/C/1

RESISTANCE WELDING CURRENT METER

Designed to measure short pulses of heavy current

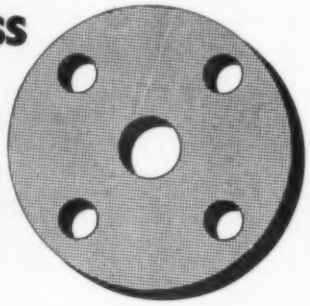
See this on STAND J24 ELECTRICAL ENGINEERS EXHIBITION Earls Court April 5-9th

The standard instrument has 6 ranges covering readings of 500 to 100,000 amps. The readings are obtained by the use of toroids which can be split and placed around the heavy current conductor. Indication is stored enabling readings to be taken minutes after the weld is made. Can be used with welders employing synchronous and non-synchronous and energy storage controls

HED

HIRST ELECTRONIC LTD.
GATWICK ROAD, CRAWLEY, SUSSEX

STAINLESS TUBES & FLANGES



We offer in approved grades of Stainless Steel

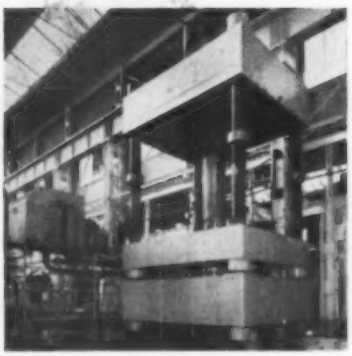
- ★ FLANGES MACHINED TO B.S. TABLES OR TO SPECIAL SIZES
- ★ SOLID DRAWN TUBES – FABRICATED PIPES
- ★ ROUND and HEXAGON BAR
- ★ PROFILES CUT TO ANY THICKNESS OR SIZE
- ★ CASTINGS TO CUSTOMERS' SPECIFICATION

Keen Prices - Prompt Delivery

Send enquires to Dept. B.W.J.

STAINLESS STEEL PROFILE CUTTERS LTD.
Farfac Works, Kings Grove, MAIDENHEAD
Telephone: 1522/23

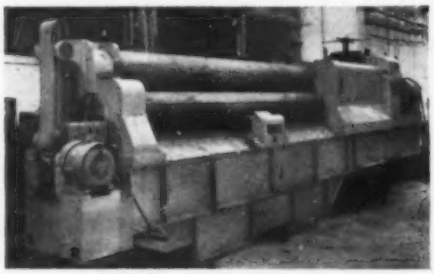
OFFER OF NEW MACHINE TOOLS FOR EARLY DELIVERY



1000 TON 4 COLUMN PRESS

This machine is for dishing the ends of boilers and pressure vessels, and has an effective table area 10 ft. square. The press is upstroking and the top table has 5-ft adjustment with a maximum vertical daylight of 10 ft.

Owing to a change in their manufacturing programme, one of our customers has asked us to sell the following 3 machine tools suitable for boiler and heavy fabrication work.



12′ × 1¼″ PLATE BENDING ROLLS

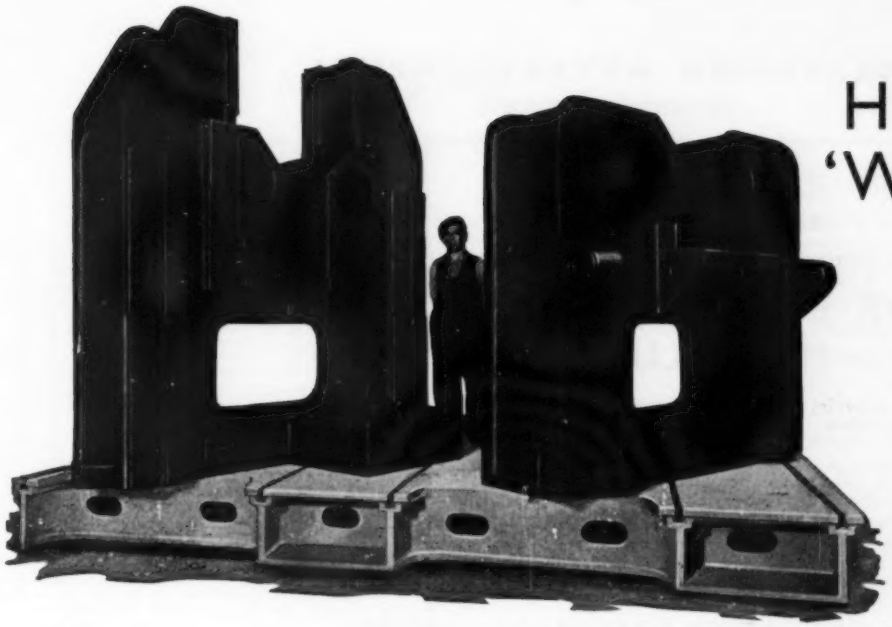
This is a horizontal pyramid type rolls, fully motorised, including the removal of the end bearing for complete circle work.

The machines can be seen in operation at any time. We shall be pleased to submit full particulars, drawings, and photographs.

2000 TON VERTICAL PLATE BENDING PRESS

For producing drums from 10 ft. long × 2¾ in. mild steel (Max.) in the cold state. This machine can preset both edges as well as automatically bend the complete circle. It is our latest patented design and has a much better performance than horizontal plate bending rolls.

HUGH SMITH & CO. (POSSIL) LTD.
Hamiltonhill Road Glasgow N2



HEAVY 'WELDINGS'

We undertake the fabrication of frames and casings for heavy machines, welded from platework and sections of our own manufacture.

The illustration shows the end housings for a flattening machine with capacity for 20" x 1½" plates.

DORMAN LONG

DORMAN LONG (*Steel*) LTD., WELDING DEPARTMENT, REDCAR, YORKS.

RESISTANCE WELDING MACHINES

A COMPREHENSIVE RANGE OF MACHINES CAN BE SEEN
IN OUR WELDING DEMONSTRATION WORKSHOP

WE INVITE YOUR ENQUIRIES

MERITUS (BARNET) LTD.

BARNET, HERTS. BAR. 2291/2

Gold Medal and Bronze Medal. Brussels World Exhibition 1958. The Engineering Centre Collective Exhibit.

CLASSIFIED ADVERTISEMENTS

APPOINTMENTS VACANT

JOSEPH LUCAS LIMITED
Group Research Centre

A vacancy exists in the Fabricating Processes Department for a

SENIOR ENGINEER, PHYSICIST or METALLURGIST

to co-ordinate the activities of a team engaged in the development of atmosphere and vacuum techniques for brazing and allied processes. The work involves establishing the underlying principles of the newer techniques and their scope for applications ranging from automobile electrical accessories to gas-turbine equipment.

Applicants should be between 25 and 35 years of age, and should have a University Degree or equivalent professional qualifications with research experience, either in industry or at University. Experience in the field of metal joining is not essential.

A good salary will be paid in accordance with age and qualifications.

Apply on writing, stating age, qualifications and experience, to the

Personnel Manager
JOSEPH LUCAS LIMITED
Great King Street, Birmingham, 19
quoting reference PM/GR/413

TUBE INVESTMENTS RESEARCH AND DEVELOPMENT DIVISION

Tube Investments invite applications for appointment to the scientific and engineering staff of their Technological Centre in Aldridge, Staffordshire. Applicants should be in the age range 24 to 35 yrs, and possess an Honours Degree or its equivalent. Previous industrial experience is desirable but not essential.

Staff are required for process research and engineering development in the following fields:

1. METALLURGY with particular reference to beryllium and other "nuclear" metals including cermets.
2. ELECTRONICS with particular reference to new techniques of inspection based on eddy current and ultrasonic measurement.
3. ELECTRICAL ENGINEERING with particular reference to automatic control mechanisms using transistor and other electronic circuits.
4. WELDING with particular reference to development of new techniques for welding.

The salary offered will be in accordance with age and experience and applications should be addressed to The Director, T.I. Technological Centre, The Airport, Walsall, Staffordshire.

TECHNICAL REPRESENTATIVES

Applications are invited from young men at present engaged on Welding Electrode development or Welding Development Projects as Technical Representatives for ESAB Limited. Vacancies exist in Scotland, West of England and East Midlands. The post carries with it a good salary, plus commissioned expenses, expenses, a non-contributory Pension Scheme and Car. Applications should be addressed to the Sales Manager, ESAB Limited, Gillingham, Kent, and addressed Confidential.

EMPYRIUM
Welding & Manufacturing Co. Ltd.

We produce fabrications, pressure vessels and chemical plant. We regard ourselves as a progressive Company and an additional factory to handle components up to 100 tons is being built.

The following appointments call for men of the highest calibre and carry appropriate salary and conditions.

Works Manager. Wide experience of the above work, a strong personality and ability to handle labour are obvious requirements. Technical qualifications, experience of incentives and cost control would prove an advantage. The real essential, however, is for a man with sound practical experience and the drive and ability to improve output whilst producing work of an increasingly high standard. Age from 35 to 45 years.

Welding Engineer. He will liaison with design and manufacture and be concerned with methods and cost reduction and we are seeking a man in the 30 to 50 age range with wide experience and an active mind.

An academic qualification in Metallurgy or Science would be an advantage.

Applications with an indication of salary required to:
Works Director, Empyrium Welding & Mfg. Co. Ltd., Pritchett Street, Aston, Birmingham 6

One "Holmes" 400/3/50, 48 h.p., five operator, 150 amp. Welding Generating Set; one "Eisler" 75 kVA. Spot & Butt Welder; eight "Metro Vick" 22·5 kVA, Atomic Hydrogen Welders; one heavy duty "Birtly" 400/3/50, Welding Manipulator with 52 in. square plate; also large stocks of stainless Steel Welding Electrodes in 6, 8, 10, 12, 14's gauge by Murex, Rockweld, and Quasi-Arc; all new in maker's original packing. Lists available. Low prices.

WOODFIELD & TURNER LTD.
Cannon Street, Burnley. Tel: 78134

Clean, fused, Unionmelt flux available, up to 2,000 lb. per week. Midlands. Box No. 241.

BRAND NEW OIL-IMMERSED OXFORD ARC WELDING TRANSFORMERS WILL GIVE YOU A LIFETIME OF SERVICE.

Fully guaranteed sets—110 amp £25, 180 amp £45, 250 amp £71, 300 amp £85, 350 amp £99 10s., 450 amp £135, etc. Also Two-operator 180, 250 and 300 amp Models, ex stock.

Send for leaflets and booklet from Britain's largest electric welding plant stockists.

C. G. & W. YOUNG
15A COLNE ROAD, TWICKENHAM.
POP. 5168

WHY are so many ENTWELD arc welding transformers purchased by the Hirers?

15 years Service has PROVED Rentweld dependability.

TODAY Rentweld value is STILL unsurpassed.

ENTWELD LTD.,
94 CAMDEN RD., LONDON, N.W.1.
ing GUL 6006/7/8

The cost of insertions in this column is 3*s.* 6*d.* a line, or 30*s.* per inch depth semi-display.

Box numbers are added for the additional charge of 2*s.* 6*d.* Replies should be addressed to Box. 000, British Welding Journal.

All matters relating to classified advertisements should be addressed to Advertisement Department, British Welding Journal, 54 Princes Gate, Exhibition Road, London, S.W.7.

Copy should be sent by 6th of each month for publication in the following month.

ADVERTISERS' INDEX

Associated Electrical Industries
Electronic Apparatus Division . . 7
Instrumentation Division . . . 12
Transformer Division . . . 29
British Industrial Gases Ltd. *Inside front cover*
British Oxygen Gases Ltd. *Outside back cover* 20
Carborundum Co. Ltd., The . . . 31
Classified 38
Crompton Parkinson (Stud Welding) Ltd. . 27
Distillers Co. Ltd., The 16
Dorman Long (steel) Ltd 37
English Electric Co. Ltd. . . . 14, 15
Firth Vickers Stainless Steels Ltd. . . 33
Hancock & Co. (Engineers) Ltd. . . 13
Harvey, G. A. & Co. (London) Ltd. . . 3
Hirst Electronic Ltd. 36
Ilford Ltd. 17
Imperial Chemical Industries Ltd. . . 5
Jenkins, Robert & Co. Ltd. . . . 32
Kodak Ltd. 10
Meritus (Barnet) Ltd. 37
Metal & Pipeline Endurance Ltd. . . 18
Metallisation Ltd. 35
Millspaugh Ltd. 34
Morris, B.O. Ltd. 11
Murex Welding Processes Ltd. . . 25
Norton Grinding Wheel Co. Ltd. . . 24
Nu-Swift Ltd. 1
Quasi-Arc Ltd. 28
Research & Control Instruments Ltd. *Inside back cover*
Robey & Co. Ltd. 2
Rubery Owen & Co. Ltd.—Rowen-Arc . 8, 9
Saturn Industrial Gases Ltd. . . . 4
Smith, Hugh & Co. (Possil) Ltd. . 30, 36
Stainless Steel Profile Cutters Ltd. . . 36
Suffolk Iron Foundry Ltd. . . . 35
Usines Balteau, S.A. 22
Wiggin, Henry & Co. Ltd. . . . 26
Yates Plant Ltd. 6

Published by THE INSTITUTE OF WELDING, 54 Princes Gate, London, S.W.7
Made and Printed by Percy Lund, Humphries & Co. Ltd., London and Bradford

Solve your production problems with

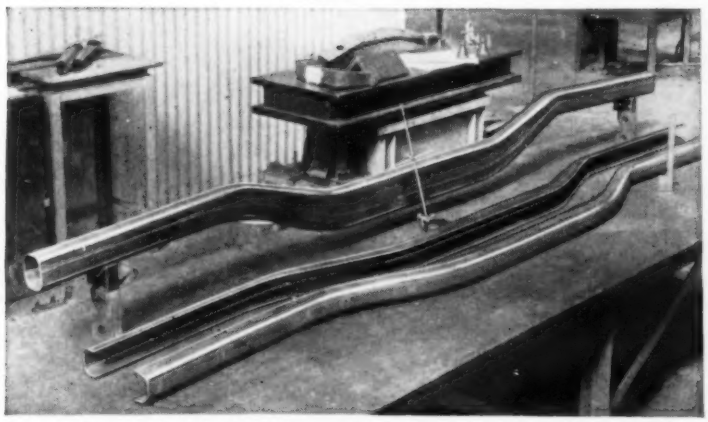
PHILIPS

bare wire

CO_2 welding machine

Philips AUTOMATIC CO_2 *bare wire* welding process is now available for immediate delivery in Britain. With this machine you can speed up mass production of welded parts, for example main chassis members, bottled gas cylinders, car wheels. And you can get welds protected from nitrogen and hydrogen by an atmosphere of CO_2 — which costs only a fraction of the price of argon. The absence of coating reduces the absorption of hydrogen, too.

- Welds very wide range of steel grades.
- Needs no stocks of expensive powders.
- Cuts labour costs by welding faster, requiring little attention in repeat operations.
- Welds are homogeneous with deep and even penetration.
- Arc is self-regulating . . .
- Nitrogen and hydrogen content low — no nitrogen porosity.



Component parts and finished vehicle chassis side member welded by Philips CO_2 process. *(Photo by courtesy of John Thompson Motor Pressings Ltd.)*

Philips Automatic CO_2 welding machine

provides automatic wire and CO_2 feeds. Travelling carriage moves along rails at speed set by operator. Water-cooled nozzle independent of main water supplies. Single control lever engages wire feed, switches on carriage motor and arc.

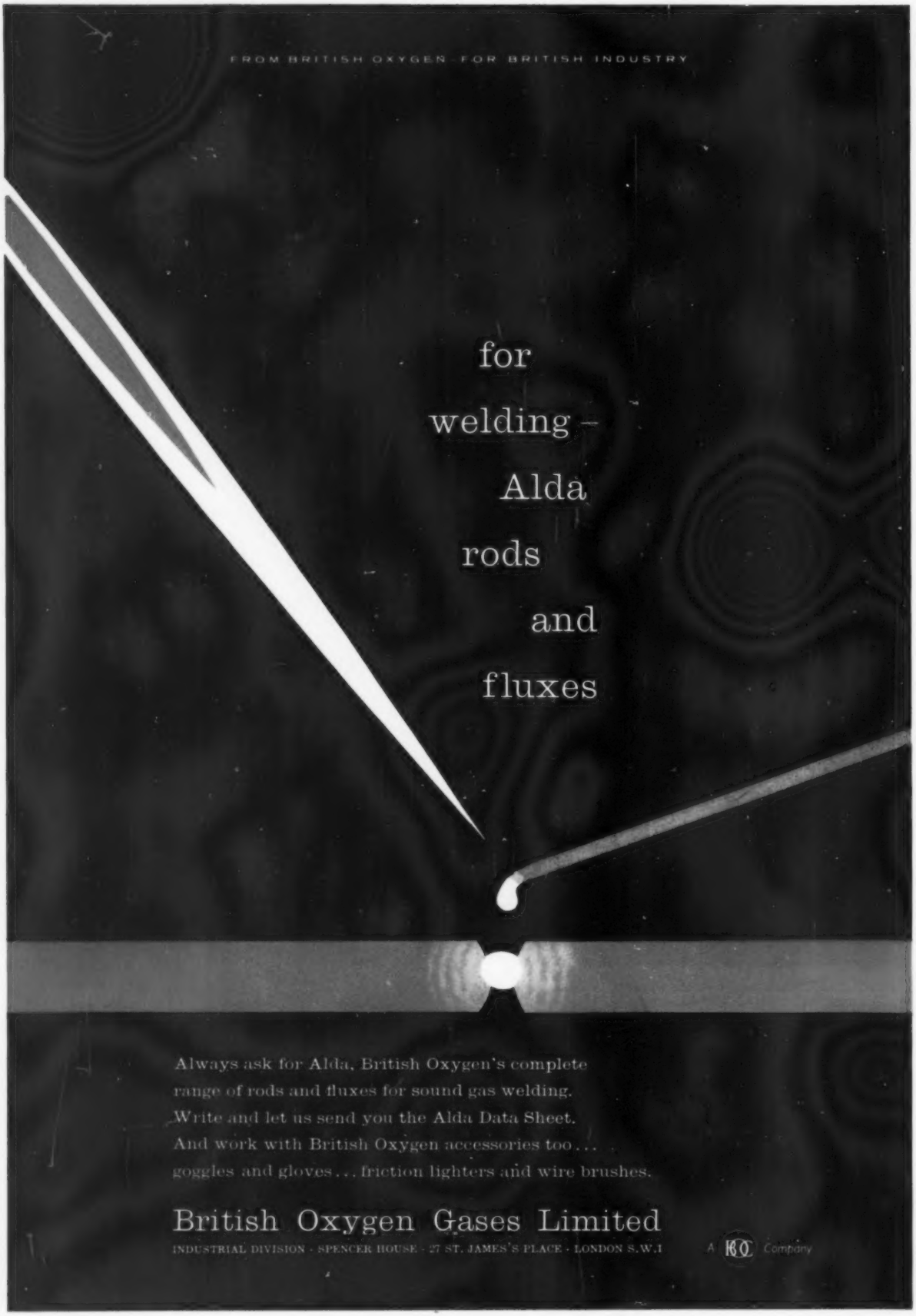
For further information about Philips CO_2 welding, and about Philips Automatic welding machine (a product of N.V. Philips, Eindhoven) write to:

Sole Distributors in the U.K.:

RESEARCH & CONTROL INSTRUMENTS LTD.

207 King's Cross Road, London. W.C.1. *Telephone : TERminus 2877.*

(P10311)


FROM BRITISH OXYGEN FOR BRITISH INDUSTRY
for
welding –
Alda
rods
and
fluxes
Always ask for Alda, British Oxygen's complete
range of rods and fluxes for sound gas welding.
Write and let us send you the Alda Data Sheet.
And work with British Oxygen accessories too...
goggles and gloves... friction lighters and wire brushes.
British Oxygen Gases Limited
INDUSTRIAL DIVISION · SPENCER HOUSE · 27 ST. JAMES'S PLACE · LONDON S.W.1
A BOC Company

Outside back cover